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Article

Structuring and empirical validation of a creative activity chain model for innovation in sustainable infrastructure development

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Abstract: This study constructs and empirically validates a Creative Activity Chain (CCA) structure model tailored for innovation in sustainable infrastructure development. In today's competitive environment, fostering innovation is crucial for maintaining the relevance and effectiveness of infrastructure projects. The research underscores that a significant portion of a project's long-term value is established during its initial concept and planning stages, highlighting the critical role of creativity in infrastructure development. The CCA model is developed through theoretical frameworks and empirical data, encompassing three key dimensions: creative subject chain, creative action chain, and creative operation chain. The model's validity is tested with data from five large infrastructure development firms in China, involving 768 R&D staff as respondents. Rigorous statistical methods, including exploratory factor analysis (EFA), confirmatory factor analysis (CFA), structural equation modeling (SEM), and regression analysis, confirm the model's robustness. The findings reveal significant positive correlations between the creative activity chain's dimensions and the successful development of sustainable infrastructure projects. Additionally, the study examines the mediating effect of link strength within the creative activity chain, demonstrating its substantial impact on project outcomes. Implications for management include promoting diverse creative teams, systematic process management, and leveraging varied operational tools to enhance creativity in infrastructure development. This research contributes to the literature by introducing an integrated model for managing creative activities in sustainable infrastructure development, offering practical insights for improving innovation processes.

Keywords: creative activity chain; sustainable infrastructure; innovation; infrastructure development; creative subject; link strength

1. Introduction

The competitive advantage of a company relies on its ability to innovate its product (Xie and Wang, 2019). New product development is essential for introducing products and services that fulfill market opportunities and customer needs (Li et al., 2021). Enterprises must constantly push the boundaries of their products, and innovation has become the lifeline for survival and development (Zhao, 2005). However, most product innovations fail not in the end but at the beginning (Zhang and Doll, 2001). New product ideas need to be supported before they become formal development projects (Khurana and Rosenthal, 1998). And 75% of the product value is determined by the idea generation, concept development stage (Hsu and Liu, 2000). Therefore, creative activities play a crucial role in the new product development process. In view of this, it is crucial for enterprises to manage creative activities in new product concept development and how to react quickly in new product development, etc. It is necessary to explore in depth the characteristics of creative activities in new product concept development in order to promote enterprises to achieve greater success in the highly competitive market. Therefore, this paper attempts to explore the activity mechanism of creative activities from the activity structure theory, to construct a creative activity chain structure model for new product concept development, and to form a breakthrough on the basis of the traditional creative model.

At present, in the research on creative activities, scholars are mostly focused on a single link to study creative activities, such as creative activities in the process focusing on the division of the stage, the research on the subjectivity of creative activities is concentrated in the study of the factors affected by themselves and the outside world, the research on the operational tools for creative activities on the application of a particular method and tool, and the research on the overall, systematic research on creative activities is relatively small, and there are even fewer studies that take new product concept development as an entry point to study creative activities. The research on creative activities with new product concept development as an entry point is even less. Therefore, this paper starts from a new perspective, integrates creative subject, creative action and creative operation, and at the same time introduces link strength as a mediating variable to further analyze the relationship between the three and the influence of the link strength within the three on the development of new product concepts. It is hoped that it can provide enterprises with more effective creative activity management methods to help them discover market opportunities and improve the competitiveness of their products.

2. Literature review and research hypothesis

2.1. Creative activity chain and structural features within them

Since Guildford (1950), a famous American psychologist, first proposed that creativity is “the ability of the most creative individual”, there has been a great deal of academic research on creativity. Different scholars have studied creativity at different levels (Amabile, 1988; Amabile et al., 2016; Guilford, 1967). The creative process, while seen as “an orderly process that begins with the discovery of new knowledge, progresses through the stages of development, and culminates in a final viable form.” However, it is by no means a simple linear generative process, but rather a multidimensional, multilevel, multifaceted chain of development (Stephen, 1985). A chain of creative activities is the collective participation in an activity that generates a common meaning and then shares the content of the activity with other new participants in order to enable the initial activity participants to generate a new activity (Liberali, 2009), thus the creative chain consists of more than two activity systems (Engeström, 2015). The significance of the new activity generation generates a creative stream because it inherits some creative goals, content and methods from the first activity (Schapper, 2010). Activity Structure Theory as a mechanism to explain the internal mechanisms of the creative activity chain, suggests that both externally and internally, it can be categorized into activities, actions as well as operations. Activities are linked to motivation and lead to the achievement of a certain purpose; activities are composed of a series of actions in order to achieve a local purpose; actions are composed of operations that conform to the conditions of the object, which can be either material tools in the case of external practical activities or formulas of logic or numerical reasoning in the case of internal thinking activities. Thus, the internal composition of the chain of creative activities is not monolithic, and their cooperation with each other directly affects the efficiency and quality of the whole. In summary, the following hypotheses were formulated for this study:

H1: creative activity chain is expressed in three dimensions: creative subject chain, creative action chain and creative operation chain.

H1a: The creative subject chain, the creative action chain and the creative operation chain positively influence each other.

2.1.1. Structural features of creative subject chain

The subject team in a project is crucial for problem solving and generating creative ideas (Thompson, 2011). Creative subjects include different participants in the creative process, including individuals, teams, and firms (Armstrong et al., 2003). Allen (1977) argued that the team structure is critical in a project because it affects not only the performance of the team, but the overall performance of the project. Yang (2021) selected core members, peripheral members to measure the creative process. Newman (2012) argued that teams provide multiple sources and different types of support, including both material and mental forms, and that diversity of members can facilitate the intersection and integration of different domains of knowledge, providing rich resources and information for the generation of new product concepts (Shin et al., 2012), Meanwhile some scholars have found that any team member can have great potential for creativity when the member possesses or perceives a high degree of cognitive diversity (Hoever et al., 2012). For the above research after making the following research hypotheses:

H2: Creative subject chain is expressed in three units: peripheral member, core member and development member.

H2a: Peripheral, core and development member positively influence each other.

2.1.2. Structural features of the creative action chain

Amabile (2016) views creativity as a process of action that involves multiple phases. Basadur (2004) suggests that creativity is a continuous and cyclical trajectory of action that involves identifying a problem, thinking about the problem, solving the problem, and implementing a new solution. Wallas (1926) also argues that creativity requires hard work to be realized. Thus, Successful innovation requires acting on novel ideas and implementing them. It also requires generating, searching, communicating and implementing ideas through subjects (Lukes and Stephan, 2017). We can understand that the creative action chain covers the whole process from idea generation to implementation on the ground, emphasizes the systematic nature of creative action, and each stage is characterized by different content. Therefore, in order to help better manage and optimize creative actions in practice, and to improve the success rate and impact, it is necessary to study and understand the creative action chain in depth. In summary, this study proposes the following hypotheses.

H3: The creative action chain is expressed in three units: idea generation, concept definition, and concept validation.

H3a: Idea generation, concept definition and concept validation positively influence each other.

2.1.3. Structural features of creative operation chain

Creative operation chain is the coordination and optimization between technical links (Chang et al., 2007). In other words, in all creative design work, the tools we use will seriously affect the nature, effectiveness and results of the work carried out (Neeley et al., 2013), which can be used not only to improve the generation of ideas (Dean et al., 2006), but also to explore and evaluate ideas. To promote the creative design process forward (Faas et al., 2014). Some scholars find that appropriate use of tools can improve work efficiency, communication among members, and understanding of problems (Bao et al., 2018; Schön et al., 1992). At the same time, some scholars have studied the effectiveness of operating tools (Vidal et al., 2004; Viswanathan et al., 2013), these research results show that tools can help generate ideas faster, and the creative operation chain can be said to run through the whole process of creative activities, but there are different requirements in each stage. Therefore, the following hypotheses are proposed in this study.

H4: The creative operation chain is expressed in three units: brainstorming, sketch prototyping and consensus assessment.

H4a: Brainstorming, sketch prototyping, and consensus assessment have positive effects on each other.

2.2. New product concept development

A product idea is a largely undefined identification of a possible product that usually exists only in the mind of its originator. A product concept is a description of a product idea that has been evaluated or is being evaluated, including shape, function, and features, which is sufficient for a person to decide to start actual development (Doyle and Piggott, 1999). New product concept development refers to a series of work from generating new product ideas to product project initiation (Murphy and Kumar, 1997). It is a series of orderly, organizable and targeted design activities based on user needs to generate conceptual products, which is represented by a process of continuous evolution from crude to fine, from vague to clear, from abstract to concrete (Li et al., 2010). Scholars distinguish product concept development from the whole product development process and define the specific content of activities in this stage (Boeddrich, 2004; Crawford and Benedetto, 2003; Cooper, 1988; Koen et al, 2001; Murphy and Kumar, 1997; Orihata and Watanabe, 2000). New product concept development is a structured and “iterative trial-and-error process” (Frishammar et al., 2013), Koenemann et al. (2017) found that in the early stages of creative activities, The sources and diversity of ideas have a significant impact on the success rate of new product concept development, and the sources of ideas include not only internal innovation, but also external innovation, such as partners, customers and users (Chrysanthouet et al., 2011). The development and realization of creativity not only need to combine the feasibility of market and technology (Paulus and Brown., 2003), but also need to have standards and methods for creative screening (Belkin et al., 2015). It can be seen that the effective operation of the creative activity chain will promote the development of new product concepts. Therefore, the following hypotheses are proposed in this study.

H5: Creative activity chain has a significant positive impact on new product concept development.

2.3. The mediating of link strength

Based on the previous overview of the structure of the chain of creative activities, using motivation, goals and tools as chains, then links are collective vulnerability links in their common context (Lemos and Liberali, 2019), nodes where creativity interchanges and flows between different stages, groups, actions and operations, that is to say, when there is a change in any one creative link, this change is transmitted through the nodes of the creative process to the whole system, which in turn affects the other links in the system. Logically, in the chain of creative activities, the closeness of the links between each stage and different sub-chains will affect each other. Therefore, these linked nodes are the key links in the creative development process, which can affect the efficiency and effectiveness of creativity, e.g., a higher degree of linkage means that it is easier for an individual to communicate effectively with other members of the creative activity chain; the evaluation results of creativity can be used for rapid decision-making and feedback; effective plan execution and optimal allocation of resources. Therefore, based on the above analysis, the hypothesis is proposed.

H6: Link strength has a mediating effect in the chain of creative activities and new product concept development.

In summary, based on the relevant theoretical foundations as well as research hypotheses, the creative activity chain model is obtained (**Figure 1**).

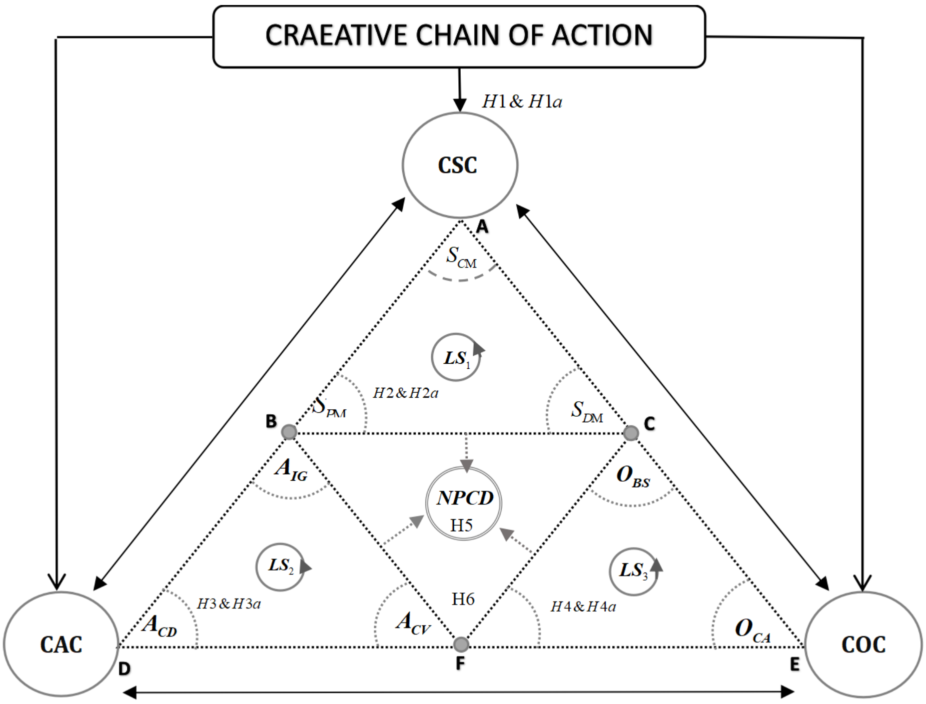

Figure 1. Creative activity chain model.

3. Research design

3.1. Research scale

In this paper, according to the suggestion of Zhen, Peng and Yang (2012) and Bollen (1989), the author refers to the scale which is now mature after testing and validation, and uses more than 3 question items for each variable in the measurement, meanwhile, finally, according to the research content and the research purpose of this paper, and combining with the actual working scenario of the research samples, the Creative Activity Chain Measurement Scale is constructed. Among them, the measurement of the creative subject chain references the research scales of Dyne and Lepine and Dyne (1998) and Zhang, Shang and Shao (2016), and 13 test items are designed. The Creative Action Chain scale references the Innovative Behavior Scale designed by TWH and Lucianetti (2015), with 11 test items are designed. The Creative Action Chain draws on the research scales of Zhang et al. (2016) and Li et al. (2016), with 15 test items designed. The measurement of link strength was designed with a total of 7 test items based on literature combing. New product concept development Zhang et al. (2016) on corporate innovation performance scale, a total of 9 test items were designed. Other variables include demographic information such as gender, age, education level, and occupation. The scales were scored on a 5-point Likert scale, with a score of 1–5 indicating an increasing level of agreement from "strongly disagree" to "strongly agree", and the higher the score, the higher the level of the variable.

3.2. Sample selection and sampling

This paper investigates manufacturing innovators in China. First, manufacturing innovators have significant advantages in terms of technology, resources, market response, innovation culture, policy support, and brand influence. Second, they are good at using unique methods to manage the creation of new knowledge (Feng et al., 2007) and accomplish the development of knowledge into new product concepts (Nonaka and Takeuchi, 1991). Thirdly, many studies have analyzed and researched the characteristics of manufacturing industries by making (He and Yuan, 2016), which provides the basis and prerequisite for studying the population characteristics of R&D personnel.

In this paper, according to the research theme and purpose, a representative sample from manufacturing innovative companies is selected for observation and analysis, so this selection was made to select research and development personnel in five large manufacturing innovative companies in this industry as the research sample, the categories are divided into project managers, process engineers, technical support personnel, software developers, mechanical and electronic designers, marketing and product management personnel, and researchers. . However, there is no fixed standard regarding the proportion of R&D personnel in the firms, so in order to improve the reliability and representativeness of the study, this paper adopts the formula proposed by Cochran (1963), which is used to derive a sufficient number of representative samples.

$$N = \frac{Z^2 pq}{e^2}$$

In calculating the sample size for the study based on Cochran's sample size equation for large populations, he assumed that $p = 0.5$ (maximum variability), q is $1 - p$, Z is the 95% confidence level, and e is the required precision of ± 5%. The final representative sample size was 384.

$$N = \frac{1.96^2 \times 0.5 \times 0.5}{0.05^2} = 384$$

Also in conjunction with what Gorsuch (1983) suggests, the capacity of the sample data should be such that the ratio of measurement questions to the number of samples should be maintained at a ratio of more than 1:5 and preferably at 1:10. However, taking into account the possibility of too small a sample size due to uncontrollable factors, such as the R&D staff's own characteristics, and the possible existence of invalid questionnaires, the ratio of the measurement items was extended to a ratio of 5–15 times, with an expected distribution of 840 copies. Finally, excluding the invalid questionnaires, a total of 768 questionnaires were recovered, and the effective recovery rate of the questionnaires was 91.4%.

3.3. Pre-research

To ensure that the questionnaire has high reliability and validity, as well as to ensure the stability of the pre-test sample, this paper will implement the pre-survey, and finally adjust the measurement items according to the results. In this paper, according to the suggestion of Wu (2010), 3–5 times of the scale items are used to determine the sample size, and MBA students are selected for the pre-survey, because this group of people whose occupational belongings have a sense of creativity, interdisciplinary thinking, communication and collaborative skills, and innovative customer orientation (Muhammed and Sathyapriya, 2019), which are basically able to fulfill the conditions and qualifications of creators' staff needed for this study. A total of 203 questionnaires were distributed and 190 questionnaires were valid, with an effective return rate of 92.6%. Firstly, the correlation coefficients between the item scores of the initial scale and the total scores with the discriminatory power were conducted for the items of each dimension; secondly, the exploratory factor analysis was conducted for the items of each dimension; and finally, the reliability analysis was conducted. Pre-research data showed that the correlation coefficients (r) between the item scores and the total scores of the initial scales of each dimension were all greater than 0.3, with a significance P-value of less than 0.05. The results of the exploratory factor analysis found that the KMO values of each dimension were all >0.5, and the P-value of Bartlett's spherical test was < 0.05, which is significant, and the cumulative contribution of extracted male factors were all >60%. The final reliability test results showed that the Cronbach's alpha coefficient of each dimension was >0.8. These data indicate that the scales of creative subject chain, creative action chain, creative operation chain, link strength and new product concept development have good reliability, as well as in the structure of the reasonableness and validity, and therefore the scale question items are all insurable and further analyzed.

4. Data analysis

4.1. Basic information statistics

The basic information of the sample, such as gender, education, length of employment and job distribution, was statistically analyzed. In terms of gender distribution, women accounted for the vast majority of respondents, amounting to 82.4%, while men accounted for 17.6%. Most of the respondents were aged between 25 and 40 years old accounting for 74%, followed by the group of 40 to 55 years old accounting for 14.6%. In terms of education level most of the respondents have a bachelor's degree, accounting for 70.7%, and master's degree holders also account for 23.6%, while college and below education and doctoral degree holders account for a relatively small percentage. In terms of time engaged in related R&D work, most respondents (69.5%) have more than three years of experience, while one to two years accounts for 9.8%. Regarding the distribution of positions, new product development researchers are the most dominant group, accounting for 49.1%, designers account for 16.8%, engineers and technical support personnel account for 13.8%, and fewer respondents are engaged in project management (5.9%).

4.2. Reliability and validity analysis

4.2.1. Reliability analysis

Firstly, according to the discriminant basis proposed by Kline (1998), a Cronbach's α coefficient >0.8 indicates good reliability. The results are shown in **Table 1**, the Cronbach's α of each construct is >0.8, which shows good internal consistency, passes the reliability test, and is suitable for further research.

Table 1. Reliability test ($N = 768$).

Dimension	Cronbach's Alpha	Number of items
Spm	0.881	5
Scm	0.871	4
Sdm	0.860	4
CSC	0.912	13
Aig	0.883	5
Acd	0.865	4
Acv	0.891	5
CAC	0.912	14
Obs	0.883	5
Osp	0.887	5
Oca	0.872	5
COC	0.924	15
LS	0.918	7
NPCD	0.936	9

4.2.2. Validity analysis

The significance levels of KMO and Bartlett's test of sphericity were used to test the suitability of the scales, and the results, as shown in **Table 2**, showed that all dimensions had a KMO value of >0.8 (> recommended value of 0.7) and $p < 0.001$, indicating that the sample's suitability was very good and suitable for validated factor analysis.

Table 2. Validity test.

Dimension	KMO Sampling Adequacy	Bartlett's Test of Sphericity		
		Approximate Chi-Square	Df	*P*-value
Spm	0.882	1865.669	10	0.000
Scm	0.831	1475.406	6	0.000
Sdm	0.829	1358.529	6	0.000
CSC	0.925	5430.036	78	0.000
Aig	0.879	1896.869	10	0.000
Acd	0.822	1448.081	6	0.000
Acv	0.876	2048.491	10	0.000
CAC	0.928	5994.741	91	0.000
Obs	0.876	1734.611	10	0.000
Osp	0.882	1973.835	10	0.000
Oca	0.883	1909.355	10	0.000
COC	0.942	6426.349	105	0.000
LS	0.934	3281.717	21	0.000
NPCD	0.959	4604.875	36	0.000

The validated factor model fit indicators were tested to meet the preset requirements (**Table 3**). Meanwhile, in the aggregation validity analysis in **Table 4**, the standardized factor loading coefficients >0.5 reached the defined criteria of Hair et al. (2017) (>0.7), the combined reliability CR > 0.6 and AVE > 0.5 also met the standard values (Fornell and Larcke,1981), and there was a good validity between the data, and the measurements were reliable. It was finally confirmed that hypotheses H1, H2, H3, and H4 were valid.

Table 3. Validated factor analysis goodness fit metrics.

CMIN	DF	CMIN/DF	*p*	GFI	AGFI	RMSEA	RMR	CFI	NFI
Judgment criteria	-	-	<3	0.000	>0.8	>0.8	＜0.08	<0.08	>0.9
1041.906	807	1.291	0.000	0.940	0.933	0.019	0.032	0.987	0.945

Table 4. Indicators of aggregation validity analysis.

Latent Variable	Item	Estimate	AVE	CR
CSC	Spm	0.765	0.624	0.833
CSC	Scm	0.797		
CSC	Sdm	0.808		
CAC	Aig	0.776	0.576	0.803
CAC	Acd	0.755		
CAC	Acv	0.745		
COC	Obs	0.771	0.648	0.846
COC	Osp	0.851		
COC	Oca	0.790		
NPCD	NPCD1	0.822	0.619	0.936
NPCD	NPCD2	0.792		
NPCD	NPCD3	0.781		
NPCD	NPCD4	0.767		
NPCD	NPCD5	0.777		
NPCD	NPCD6	0.788		
NPCD	NPCD7	0.769		
NPCD	NPCD8	0.790		
NPCD	NPCD9	0.792		
LS	LS1	0.808	0.616	0.918
LS	LS2	0.820		
LS	LS3	0.804		
LS	LS4	0.739		
LS	LS5	0.756		
LS	LS6	0.804		
LS	LS7	0.761		
Osp	Osp5	0.815	0.611	0.887
Osp	Osp4	0.722		
Osp	Osp3	0.767		
Osp	Osp2	0.786		
Osp	Osp1	0.816		
Oca	Oca5	0.799	0.604	0.884
Oca	Oca4	0.753		
Oca	Oca3	0.818		
Oca	Oca2	0.748		
Oca	Oca1	0.765		
Obs	Obs5	0.758	0.578	0.873
Obs	Obs4	0.772		
Obs	Obs3	0.760		
Obs	Obs2	0.744		
Obs	Obs1	0.767		

Table 4. (*Continued*).

Latent Variable	Item	Estimate	AVE	CR
Acv	Acv5	0.798	0.620	0.891
Acv	Acv4	0.773		
Acv	Acv3	0.796		
Acv	Acv2	0.776		
Acv	Acv1	0.795		
Acd	Acd4	0.794	0.619	0.866
Acd	Acd3	0.677		
Acd	Acd2	0.833		
Acd	Acd1	0.832		
Aig	Aig5	0.752	0.601	0.883
Aig	Aig4	0.790		
Aig	Aig3	0.780		
Aig	Aig2	0.761		
Aig	Aig1	0.793		
Spm	Spm5	0.773	0.598	0.881
Spm	Spm4	0.756		
Spm	Spm3	0.806		
Spm	Spm2	0.762		
Spm	Spm1	0.768		
Scm	Scm4	0.799	0.629	0.871
Scm	Scm3	0.753		
Scm	Scm2	0.823		
Scm	Scm1	0.796		
Sdm	Sdm4	0.787	0.608	0.861
Sdm	Sdm3	0.758		
Sdm	Sdm2	0.799		
Sdm	Sdm1	0.775		

4.3. Correlation analysis

In this study, SPSS test was used to mainly investigate the correlation between the variables, to calculate the correlation coefficient between the variables and to determine whether the correlation between the variables is significant or not. As can be seen in **Tables 5–7**, the correlation coefficient values between CSC and Spm, Scm, Sdm, between CAC and Aig, Acd, Acv, and between COC and Obs, Osp, and Oca were well behaved and significant at $p < 0.01$, having a correlation.

Table 5. Creative subject chain (CSC) correlation analysis.

	CSC	Spm	Scm	Sdm
CSC	1			
Spm	0.848**	1		
Scm	0.838**	0.550**	1	
Sdm	0.820**	0.534**	0.561**	1

* $p < 0.05$ ** $p < 0.01$.

Table 6. Creative action chain (CAC) correlation analysis.

	CAC	Aig	Acd	Acv
CAC	1			
Aig	0.834**	1		
Acd	0.791**	0.509**	1	
Acv	0.828**	0.509**	0.496**	1

* $p < 0.05$ ** $p < 0.01$.

Table 7. Creative operation chain (COC) correlation analysis.

	COC	Obs	Osp	Oca
COC	1			
Obs	0.817**	1		
Osp	0.872**	0.578**	1	
Oca	0.843**	0.520**	0.610**	1

* $p < 0.05$ ** $p < 0.01$.

4.4. Hypothesis testing

4.4.1. Regression analysis

This study utilized SPSS to perform regression analysis of the study variables and finalize the test results.

(1) Creative activity chain (CCA)

Tables 8–10 report the regression results of the correlation between the creative subject chain, the creative action chain, and the creative operation chain. As can be seen from the regression results in **Table 8**, when COC and CAC are taken as independent variables and CSC is taken as dependent variables for linear analysis, $\beta = 0.203$ ($t = 8.426$, $p < 0.01$) for creative action chain and $\beta = 0.304$ ($p < 0.01$) for creative operation chain, indicating that creative operation chain, and creative action chain both positively contribute to creative subject chain. From the regression results in **Table 9**, it can be seen that when the CSC, COC is the independent variable and the CAC is the dependent variable in the analysis, $\beta = 0.202$ ($p < 0.01$) for the creative subject chain, and $\beta = 0.299$ ($p < 0.01$) for the creative operation chain, which surfaces that the creative subject chain, and the creative operation chain will both positively promote the creative action chain. From the regression results in **Table 10**, it can be seen that when CAC, CSC is used as the independent variable and COC is used as the dependent variable in the regression analysis, $\beta = 0.283$ ($p < 0.01$) for the creative action chain, and $\beta = 0.286$ ($p < 0.01$) for the creative subject chain, which surfaces that both the creative action chain, and the creative subject chain will positively promote the creative operation chain. In summary, the above analysis finally supports hypothesis H1a that creative subject chain, creative action chain and creative operation chain produce significant positive correlation with each other.

Table 8. CSC linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.649	0.140	-	11.771	0.000**	-
COC	0.304	0.036	0.302	8.547	0.000**	1.164
CAC	0.203	0.035	0.202	5.721	0.000**	1.164
R^2	0.178					
Adjusted *R* Square	0.176					
F	F (2, 766) = 82.890, p = 0.000					

Dependent Variable: CSC.
* $p < 0.05$ ** $p < 0.01$.

Table 9. CAC linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.758	0.138	-	12.750	0.000**	-
CSC	0.202	0.035	0.203	5.721	0.000**	1.167
COC	0.299	0.036	0.298	8.426	0.000**	1.167
R^2	0.176					
Adjusted *R* Square	0.174					
F	F (2, 766) = 81.746, p = 0.000					

Dependent Variable: CAC.
* $p < 0.05$ ** $p <0.01$.

Table 10. COC linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	***Beta***			
Constant	1.503	0.137	-	10.949	0.000**	-
CAC	0.283	0.034	0.284	8.426	0.000**	1.111
CSC	0.286	0.033	0.288	8.547	0.000**	1.111
R^2	0.215					
Adjusted *R* Square	0.213					
F	F (2, 766) = 105.209, p = 0.000					

Dependent Variable: COC.
* $p < 0.05$ ** $p < 0.01$.

(2) Creative subject chain (CSC)

Tables 11–13 report the regression results for the correlation between peripheral, core, and developmental members. As can be seen from the regression results in **Table 11**, analyzing Scm, Sdm as the independent variables and Spm as the dependent variable, Scm has $\beta = 0.326$ ($t = 10.626$), $p < 0.01$, and Sdm has $\beta = 0.311$

(t = 9.525), $p < 0.01$, which suggests that core and developmental memberships positively contribute to peripheral membership. As can be seen from the regression results in **Table 12**, analyzing Spm, Sdm as the independent variables and Scm as the dependent variable, β = 0.394 (t = 10.626, $p < 0.01$) for Spm and β = 0.398 (t = 11.316, $p < 0.01$) for Sdm, implying that both peripheral, and developmental member will positively promote core member. As can be seen from the regression results in **Table 13**, analyzing Scm, Spm as the independent variables and Sdm as the dependent variable, β = 0.359 (t = 11.316, $p < 0.01$) in Scm; and β = 0.340 (t = 9.525, $p < 0.01$) in Spm, which suggests that both core, and peripheral member will positively promote development member. In summary, the above analysis finally supports hypothesis H2a, which states that core, peripheral, and developmental members produce a significant positive correlation with each other.

Table 11. Spm linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.383	0.103	-	13.441	0.000**	-
Scm	0.326	0.031	0.366	10.626	0.000**	1.459
Sdm	0.311	0.033	0.328	9.525	0.000**	1.459
R^2	0.377					
Adjusted R Square	0.375					
F	F (2, 766) = 231.354, p = 0.000					

Dependent Variable: Spm.
* $p < 0.05$ ** $p < 0.01$.

Table 12. Scm linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	0.470	0.125	-	3.767	0.000**	-
Spm	0.394	0.037	0.351	10.626	0.000**	1.398
Sdm	0.398	0.035	0.374	11.316	0.000**	1.398
R^2	0.403					
Adjusted *R* Square	0.401					
F	F (2, 766) = 258.119, p = 0.000					

Dependent Variable: Scm.
* $p < 0.05$ ** $p < 0.01$.

Table 13. Sdm linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.102	0.113	-	9.777	0.000**	-
Scm	0.359	0.032	0.383	11.316	0.000**	1.434
Spm	0.340	0.036	0.323	9.525	0.000**	1.434
R^2	0.387					
Adjusted *R* Square	0.386					
F	F (2, 766) = 241.932, p = 0.000					

Dependent Variable: Sdm.
* $p < 0.05$ ** $p < 0.01$.

(3) Creative action chain (CAC)

Tables 14–16 report the regression results of the correlation between idea generation, concept definition, and concept validation. As seen from the regression results in **Table 14**, analyzing concept definition, concept validation as independent variables and idea generation as dependent variable, $\beta = 0.330$ ($p < 0.01$) for concept definition and $\beta = 0.344$ ($p < 0.01$) for concept validation, indicates that both concept definition, concept validation positively contribute to idea generation. As seen in **Table 15**, analyzing idea generation, concept validation as the independent variable and concept definition as the dependent variable, $\beta = 0.357$, $p < 0.01$ for idea generation, and $\beta = 0.332$, $p < 0.01$ for concept validation, indicating that both idea generation, and concept validation positively promote concept definition. As seen in **Table 16**, analyzing idea generation, concept definition as independent variables and concept validation as dependent variable, β = 0.344 ($p < 0.01$) for idea generation and $\beta = 0.307$ ($p < 0.01$) for concept definition, indicating that both idea generation and concept definition will positively promote concept validation. In summary, the final results of the analysis support Hypothesis H3a, which states that idea generation, concept definition, and concept validation produce a significant positive correlation with each other.

Table 14. Aig linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.041	0.121	-	8.620	0.000**	-
Acd	0.330	0.033	0.340	10.115	0.000**	1.326
Acv	0.344	0.034	0.341	10.127	0.000**	1.326
R^2	0.346					
Adjusted *R* Square	0.345					
F	F (2, 766) = 203.062, p = 0.000					

Dependent Variable: Aig.
* $p < 0.05$ ** $p < 0.01$.

Table 15. Acv linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	0.972	0.127	-	7.671	0.000**	-
Aig	0.357	0.035	0.346	10.115	0.000**	1.350
Acv	0.332	0.036	0.319	9.320	0.000**	1.350
R^2	0.334					
Adjusted *R* Square	0.333					
F	F (2, 766) = 192.479, p = 0.000					

Dependent Variable: Acd.
* $p < 0.05$ ** $p < 0.01$.

Table 16. Acd linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	***Beta***			
Constant	1.419	0.116	-	12.272	0.000**	-
Aig	0.344	0.034	0.347	10.127	0.000**	1.350
Acd	0.307	0.033	0.319	9.320	0.000**	1.350
R^2	0.335					
Adjusted *R* Square	0.333					
F	F (2, 766) = 192.632, p = 0.000					

Dependent Variable: Acv.
* $p < 0.05$ ** $p < 0.01$.

(4) Creative operation chain (COC)

Tables 17–19 report the regression results of the correlation between brainstorming, sketch prototyping, and consensus assessment. As seen in **Table 17**, analyzing sketch prototyping, consensus assessment as independent variables and brainstorming as dependent variable, $\beta = 0.366$ ($p < 0.01$) for sketch prototyping and $\beta = 0.249$ ($p < 0.01$) for consensus assessment implies that both sketch prototyping, and consensus assessment positively promote brainstorming. As seen in **Table 18**, analyzing consensus assessment brainstorming as independent variables and sketch prototyping as dependent variable, $\beta = 0.446$ ($p < 0.01$) for sketch prototyping; and $\beta = 0.404$ ($p < 0.01$) for brainstorming, which indicates that both consensus assessment, and brainstorming will positively promote sketch prototyping. As seen in **Table 19**, analyzing sketch prototyping and brainstorming as independent variables and consensus assessment as dependent variable, $\beta = 0.441$, ($p < 0.01$) for sketch prototyping and $\beta = 0.272$, ($p < 0.01$) for brainstorming implies that both sketch prototyping and brainstorming will positively promote consensus assessment. In summary, the final results of the analysis support hypothesis H4a, which states that sketch prototyping, brainstorming, and consensus assessment produce a significant positive correlation with each other.

Table 17. Obs linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.430	0.102	-	14.074	0.000**	-
Osp	0.366	0.032	0.414	11.539	0.000**	1.591
Oca	0.249	0.033	0.268	7.455	0.000**	1.591
R^2	0.379					
Adjusted *R* Square	0.377					
F	F (2, 766) = 233.586, p = 0.000					

Dependent Variable: Obs.
* $p < 0.05$ ** $p < 0.01$.

Table 18. Osp linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	***Beta***			
Constant	0.430	0.119	-	3.623	0.000**	-
Oca	0.446	0.033	0.424	13.682	0.000**	1.371
Obs	0.404	0.035	0.357	11.539	0.000**	1.371
R^2	0.465					
Adjusted *R* Square	0.463					
F	F (2, 766) = 332.362, p = 0.000					

Dependent Variable: Osp.
* $p < 0.05$ ** $p < 0.01$.

Table 19. Oca linear regression.

	Unstandardized Coefficients		**Standardized Coefficients**	***t***	***p***	**VIF**
	B	**Std. Error**	**Beta**			
Constant	1.000	0.113	-	8.820	0.000**	-
Osp	0.441	0.032	0.464	13.682	0.000**	1.501
Obs	0.272	0.036	0.253	7.455	0.000**	1.501
R^2	0.414					
Adjusted *R* Square	0.413					
F	F (2, 766) = 270.653, p = 0.000					

Dependent Variable: Oca.
* $p < 0.05$ ** $p < 0.01$.

4.4.2. SEM test

Following the validation factor test, the structural equation model (SEM) was constructed as shown in **Figure 2**. The model's fit was tested against several goodness-of-fit criteria, and the results are summarized in **Table 20**. Most of the fit indices meet the standard requirements, indicating that the theoretical model constructed in this study is well-fitted and acceptable.

Table 20. Model fit analysis.

	CMIN	**DF**	**CMIN/DF**	***p***	**GFI**	**AGFI**	**RMSEA**	**RMR**	**CFI**	**NFI**
Optimal Criterion	-	-	<3	-	>0.8	>0.8	<0.08	<0.08	>0.9	>0.9
	2023.42	1576	1.284	0.000	0.919	0.912	0.019	0.032	0.983	0.928

As **Table 20** demonstrates, the majority of the fitted parameters meet or exceed the optimal criteria, confirming that the model is a good fit for the data. This suggests that the theoretical model proposed in the study can be accepted as an appropriate representation of the underlying relationships.

In addition, the related path analysis results are presented in **Table 21**. The significant *P*-values for the three elements of the creative activity chain—creative subject chain, creative action chain, and creative operation chain—on link strength and new product development concept were all less than 0.05. The standardized values were between 0 and 1, indicating that the creative activity chain has a positive and significant influence on both link strength and new product development concept. Furthermore, the standardized value of the path from link strength to new product development concept was also within the 0 to 1 range ($p < 0.05$), signifying that link strength has a positive and significant effect on the new product development concept. Based on these findings, hypothesis H5 is supported.

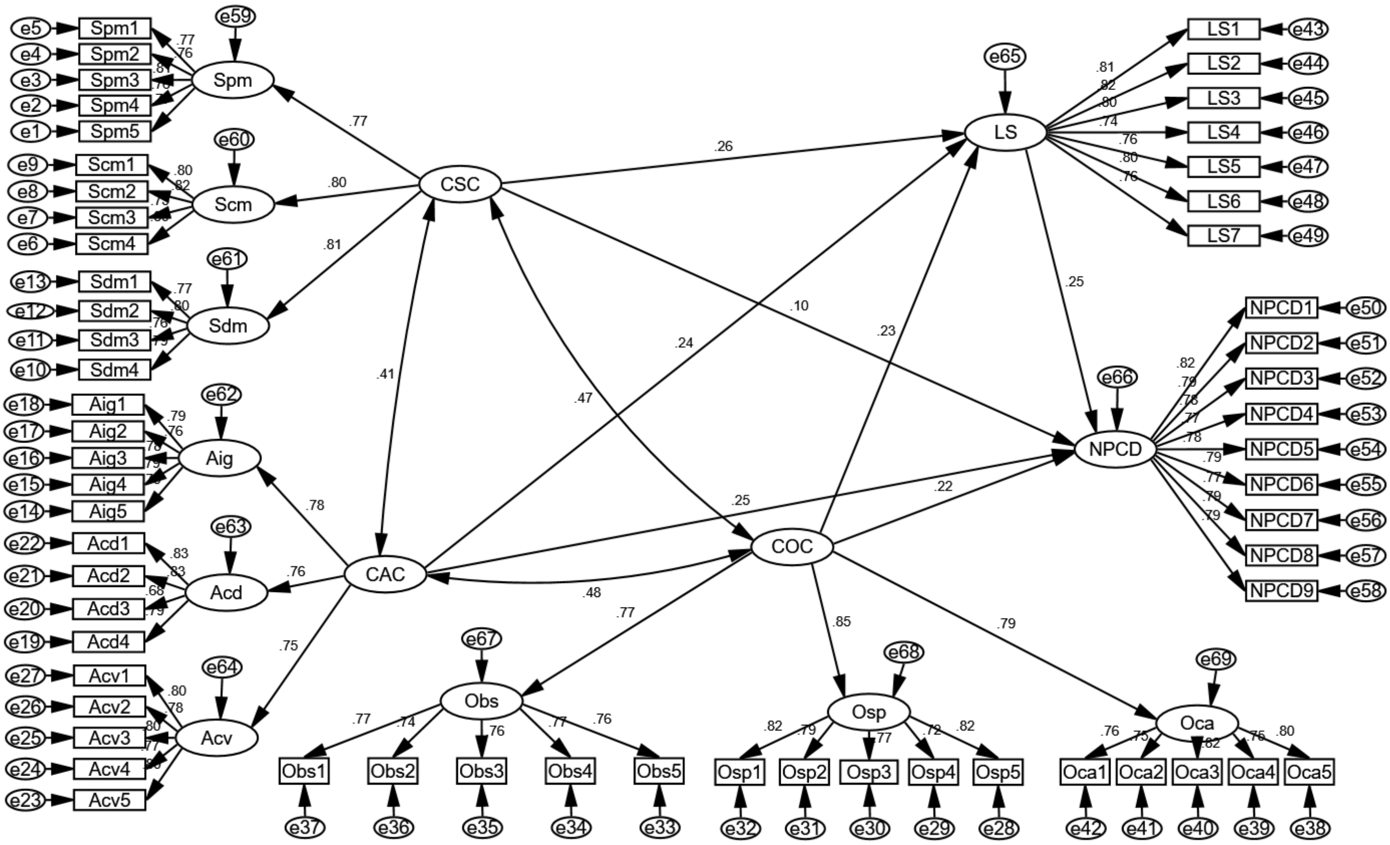

Figure 2. Structural equation modeling diagram.

Table 21. Path coefficient test.

Route			Unstandardized Coefficient	Standardized Coefficient	S.E.	C.R.	*p*
LS	←	CSC	0.407	0.264	0.074	5.538	***
LS	←	CAC	0.361	0.238	0.073	4.924	***
LS	←	COC	0.371	0.228	0.079	4.686	***
NPCD	←	CSC	0.139	0.100	0.062	2.246	0.025
NPCD	←	LS	0.225	0.250	0.037	5.991	***
NPCD	←	CAC	0.336	0.247	0.064	5.241	***
NPCD	←	COC	0.324	0.222	0.068	4.758	***

***$p < 0.001$.

Although SEM provides a robust method for testing the relationships within the model, it may not fully capture the broader dimensions of co-creation in the context of cultural outcomes. To enhance the model, it would be beneficial to integrate a framework of indicators that goes beyond exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and SEM. Specifically, future research could consider incorporating Co-Creation Analysis (CCA), which emphasizes the joint creation of value by the company and the customer. As highlighted by Prahalad and Ramaswamy (2000), co-creation allows customers to co-construct the service experience to better suit their context. This involves co-designing, co-constructing, co-evaluating, and even co-funding the experience, elements that may provide a deeper understanding of the cultural outcomes and the collaborative nature of innovation in new product development.

By extending the current framework to account for co-creation, future studies may explore how co-creation influences the relationship between creative activity chains and new product development concepts, particularly through the lens of cultural and contextual factors.

4.4.3. Mediation effect test

Bootstrap processing analysis was used in this study to test the mediating effect of link strength. The test results are shown in **Table 22**, the direct effect [0.202, 0.454] and indirect effect [0.191, 0.342] in the 95% confidence interval of the creative subject chain do not contain 0, which indicates that there is a mediating effect of the link strength in the creative subject chain with the concept development of the new product. Neither the direct effect [0.323, 0.619] nor the indirect effect [0.155, 0.296] in the 95% confidence interval of the creative action chain contains 0, indicating that there is a mediating effect of link strength in the creative action chain with new product concept development. Neither the direct effect [0.355, 0.642] nor the indirect effect [0.175, 0.330] in the 95% confidence interval of the creative action chain contains 0, indicating that there is a mediating effect of link strength in the creative action chain with new product concept development. At the same time, according to the previous verification results for hypothesis H1, we can finally get that hypothesis H6 is established.

Table 22. Intermediate effect test.

Effect Type	Path Relationship	Effect Value	SE	Bias-Corrected 95%CI		Percentile 95% CI		Effect Proportion (%)
				Lower	Upper	Lower	Upper	
Total	CSC → NPCD	0.584	0.067	0.458	0.715	0.458	0.715	
Direct	CSC → NPCD	0.324	0.064	0.202	0.454	0.200	0.453	55.48
Indirect	CSC → LS → NPCD	0.260	0.038	0.191	0.342	0.190	0.340	44.52
Total	CAC → NPCD	0.683	0.076	0.545	0.843	0.543	0.842	
Direct	CAC → NPCD	0.465	0.074	0.323	0.619	0.325	0.621	68.08
Indirect	CAC → LS → NPCD	0.218	0.036	0.155	0.296	0.152	0.294	31.92
Total	COC → NPCD	0.736	0.073	0.598	0.885	0.597	0.881	
Direct	COC → NPCD	0.493	0.074	0.355	0.642	0.355	0.642	66.98
Indirect	COC → LS → NPCD	0.243	0.04	0.175	0.330	0.170	0.326	33.02

5. Conclusion

5.1. Empirical findings

In this paper, the correlation between the creative activity chain and new product concept development, and the mediating role of link strength are explored with 768 R&D personnel in innovative companies. The final empirical findings illustrate that the results of the validated factor analysis of the creative activity chain model proposed in this study demonstrate that the third-order validated factor model of the creative activity chain has a good fit (**Table 3**), and that the model construction is in line with the data results, i.e., hypotheses H1, H2, H3, and H4 hold. The data from the correlation (**Tables 5–7**) and regression analysis (**Tables 8–19**) supported the influential relationship between the creative activity chain, creative subject chain, creative action chain, and creative operation chain, i.e., H1a, H2a, H3a, and H4a were established. Meanwhile, through the structural equation modeling (**Figure 2**) as well as the goodness of fit (**Table 20**) and path analysis (**Table 21**), the creative subject chain, the creative action chain and the creative operation chain are positively and significantly influencing relationships on the concept of new product development, which, combined with the validation of Hypothesis H1, can lead to the conclusion that Hypothesis H5 is also valid. Finally, after the mediation test through Bootstrap, it is found that there is a mediation effect of link strength in creative subject chain, creative action chain and creative operation chain and new product concept development, combined with hypothesis H1 verification, it can be concluded that hypothesis H6 is established.

5.2. Management implications

This study has certain guiding significance for enterprise R&D personnel, policy makers and other stakeholders.

1) High-quality creativity often comes from diverse creative participants. Creative subjects not only come from different specialties, positions, etc., and are not limited to internal enterprises, but also come from outside the enterprise, so external cooperation should be actively sought, which helps to introduce new perspectives and ways of thinking. Enterprises should attach importance to cooperation, and actively create an atmosphere of internal communication and knowledge sharing. 2) Attention to the management and control of each link, enterprises should establish a systematic creative process management procedures, clear objectives, tasks and responsibilities at each stage, and at the same time do a good job of progress tracking and risk control, and provide timely feedback and follow up on potential problems or problems that have already appeared. 3) Establish a scientific evaluation standard and process to ensure that high-potential creativity can be discovered. 4) Different operating tools can stimulate different creative methods and ways of thinking, so it is recommended to use a variety of tools in the new product development process will help to improve the quality of ideas. 5) Establish a flexible regulatory system to coordinate the main body, actions and tools to optimize the chain of creative activities, to help companies and team members more effectively manage the development of new product concepts, and to ensure that each link efficient operation.

5.3. Limitations

The creative activity chain model developed in this paper offers a novel integration of subjects, actions, and operations, spanning multiple departments, teams, and stages of the development process. However, this integration comes with limitations. Firstly, the model may not fully account for the complexity inherent in the new product development process, particularly given the uncertainties related to market demand, competitive pressures, and rapid technological changes. This limitation could hinder the model's ability to effectively manage and coordinate unexpected situations or adapt to highly dynamic environments.

Moreover, since the Creative Activity Chain model is based on the research subject's actual work practices, the understanding and application of the model are likely influenced by personal experience, cultural background, and situational factors. This could introduce a degree of subjectivity, limiting the model's objectivity and generalizability across different contexts.

Additionally, this study focuses on an industry characterized by high-tech products, which may not be representative of other sectors. As such, the applicability of the findings to other industries and enterprises is uncertain. Future research is needed to explore whether the conclusions drawn from this study can be generalized across a wider range of industries. This should include consideration of the capacity of industry brands, the categories of products, and the availability of other resources within enterprises, ensuring that the model can be effectively adapted to diverse contexts.

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