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Factors Associated with Creativity among STEM Learners: A Structural Equation Modeling Approach

FAN Yaqin [a], Jacob Owusu Sarfo [b, c, d, e, *]

[a] Tianjin Academy of Educational Science, Tianjin, China
[b] University of Cape Coast, Cape Coast, Ghana
[c] Centre for Behaviour and Wellness Advocacy, Koforidua, Ghana
[d] Cherkas Global University, Washington, DC, USA
[e] Volgograd State University, Volgograd, Russian Federation

Abstract

As an effective way of cultivating technologically innovative talents, STEM education is gradually becoming the core driving force of innovative education. The key issues currently focused on by educators include analysing the factors influencing STEM innovation talents, exploring the training mechanism, and even promoting the educational revolution of talent cultivation. In this study, we adopted a structural equation modelling approach to explore class- and individual-level factors associated with creativity among STEM learners. Our study sample included 234 Chinese Junior High School students (Female = 51.71 %, Male = 48.29 %). Results indicated positive correlations between activity rules, personal characteristics, and division of tasks and creativity for STEM learners. Among them, activity rules had a stronger effect on personal characteristics compared to the division of tasks. The direct influence of the value of activity rules on personal characteristics was larger than that of creativity for STEM learners. Compared to personal characteristics, activity rules had a smaller effect value on creativity for STEM learners but a larger effect of total influence. The division of tasks was mediated by personal characteristics, which had a positive, albeit weak, effect on both personal characteristics and creativity for STEM learners. Findings from the study have implications for STEM education, policy, and research.

Keywords: creativity, junior high students, personal characteristics, STEM learners, structural equation modelling.

* Corresponding author
E-mail addresses: jacob.sarfo@ucc.edu.gh (J.O. Sarfo)

1. Introduction

Whether in the past, present, or future, people will always face a wide variety of problems to solve in their lives, and the types and content of these problems are unpredictable. Creative problem-solving is considered an essential life and work skill for the 21st century (EU Commission Council, 2018; Williamson, 2001; World Bank, 2019). More and more people are beginning to recognise the vital value of creative cultivation (Organization for Economic..., 2019; Soh, 2017). Creativity is typically considered as the power or ability to create and produce, and the result can be abstract ideas or materialised products or solutions (Lubart, Sternberg, 1998; Paletz, Peng, 2008; Rhodes, 1961; Runco, 1999).

1.1. Creativity for science, technology, engineering and mathematics students

Science, technology, engineering and mathematics (STEM) education combines multi-disciplinary and inter-disciplinary experiences to gain knowledge and skills (Lamb et al., 2015). The integration of these multi-disciplinary approaches could enhance students' creativity in addressing real-life problems (Eroğlu, Bektaş, 2022; Nemiro et al., 2017; Shaughnessy, 2013). For example, Kuo et al. (2019) conducted an 18-week STEM Interdisciplinary Project-based Learning course for 45 college students. Results from their study showed a significant improvement in students' creativity. Additionally, after taking the course, students could think faster, develop more ideas and put more details into their thinking. Another study by Yalçın et al.(2021) among 39 children over eight weeks to verify the impact of preschool STEM educational activities on children's creativity showed a significant enhancement in creativity scores in the experimental group. However, the results indicated no significant difference in the control group. The meaningful relationship between STEM education and creativity makes more sense to explore the creativity of STEM students. Thus, STEM students can acquire the knowledge to integrate different subject systems to create new products (Henriksen, 2014). These findings also support the assertion that STEM education can foster the development of learner's creativity since it focuses on cultivating creativity (Harris, Bruin, 2018).

1.2. Critical influential factors for creativity

Human beings have never ceased to explore creativity and its associated factors to uncover the mysteries of creation and gain the power to transform the world. Weng et al. (2022) study showed that maker education based on realistic problems could build scaffolding for students' creativity. Students can perceive the support for creativity from the educational environment, which can be divided into cognitive, social, motivational and cultural scaffolding (Maksić, Jošić, 2021). It is a widely accepted belief that the availability of more choices could stimulate creativity, as it offers a greater range of potential solutions to problems (Sellier, Dahl, 2011). Likewise, unlimited freedom can boost people's desire to create more. However, in some specific disciplinary areas, for example, a creative writing course, clear limits are more conducive to innovation (Tromp, Baer, 2022). Correspondingly, Zhu et al. (2023) argued that there was a positive correlation between reappraisal and creativity. However, Mack et al. (2021) believed that abilities, personality traits, and skills were the key factors in nurturing natural science talents. Moreover, from the family perspective, parents' positive parenting style was more beneficial for children's creativity development (Dong et al., 2022).

Another important assertion worth noting is that the creativity of humans is not isolated but closely related to the social environment in which people find themselves. New ideas emerged from interactions with the environment and others (Glaveănu, 2010; Zhang et al., 2021). The creativity of humans is the result of the interaction between individuals and social culture, supported or limited by the external environment (Glaveănu, 2010). As mentioned earlier, most previous studies had focused on specific factors such as courses, external environment, family, and individuals, and few had comprehensively understood factors inside and outside the classroom. This research focused on the classroom and individual as a whole to study their joint interaction with creativity for STEM learners (CfSl).

1.3. Research model

From the Activity Theory Perspective, if STEM learning of students is viewed as an activity system, then factors at the class level include tools, rules, and labour division required for the activity. Individual factors are the learning characteristics of individual students. The goal of the activity is to cultivate innovative talents in STEM.

Activity tools

The COVID-19 pandemic has led to the rapid development of online teaching. For all its problems, it has crept into the educational horizon and reversed its position as a substitute for offline instruction. The inclusion of network teaching has gradually changed the teaching centre from teaching to learning, from classroom learning to various learning modes, effectively making up for the shortage of high-quality resources and providing a new way for the development of high-quality basic education (Almahasees et al., 2021; Sulaiman, 2014). However, certain challenges are associated with online learning, such as low communication efficiency and limited interaction (Sjølie et al., 2022; Janssen, Kirschner, 2020). The interaction between teachers and students in offline classrooms provides an opportunity for face-to-face sharing of online experiments and results and enhances the feeling between teachers and students to make up for the lack of emotion in online learning (Kear, 2010; Kear et al., 2012). Both online and offline classrooms have their advantages and disadvantages. One of the issues addressed in this study is how these two types of classrooms integrate to give full play to their strengths. Therefore, this study uses both online and offline resources as instrumental indicators of STEM learning activities to investigate the impact of these two types of resources on STEM innovative talent. Specific activity tool indicators considered in the study included the following six elements: digital resources, virtual STEM programs, online communication, paper resources, real STEM programs, and face-to-face communication.

Activity rules

Problem-solving is a process of discovering the unknown. Important questions bothering problem-solving include: how do we nurture innovative talent, and what kind of learning inspires students to be innovative? To explore these issues, examining the rules guiding innovative, original problem-solving skills is important. Creativity comes from the exploration and perception of the unknown. Many scholars at home and abroad have provided general steps for problem-solving. A popular example is the four stages proposed by Basadur and his colleagues: problem generation, problem definition, program design and program implementation (Branford, Stein, 1993). Despite this, it is still unclear how the problem was solved and designed and what crucial thinking the problem solver went through in designing and implementing the solution.

According to Jäkel and Schreiber (2013), reflection can explain this question and point out that reflection is to rethink and reflect on the entire process of problem-solving to gain new experiences of problem-solving and systematically perceive the entire problem-solving approach. This approach will help individuals to solve the key problems and readjust the solutions (Jäkel, Schreiber, 2013). Furthermore, questioning has been recognised as an effective cognitive strategy during problem-solving design or introspection (Browne, Keeley, 2007). Of these, self-questioning has the least limited use. In addition, the relationship between the original cognitive structure of the problem solver and the problem is also the key information for the problem to be solved in problem-solving (Browne, Keeley, 2007; Wang, Chiew, 2010; Wu, Molnár, 2022). It can promote further understanding of the problem by the problem solver and then transfer knowledge through mining the correlation between knowledge and obtaining problem-solving solutions. Thus, this study sets the activity rules for STEM learning activities as three elements: reflection, self-questioning, and association mining.

Division of tasks

Division of tasks in a STEM project is the separation of roles in which community members' functions, attributes and responsibilities are described. Whether STEM education or innovative talent cultivation, both emphasise the student-centred teaching model and pay attention to the flexible, free and equal environment (Anjur, 2011), which shows an equal and independent relationship between students and teachers in cultivating STEM innovative talents. That is, the teacher takes on the work of teaching and instruction, and the student takes on the task of independent learning. Students are project/problem-oriented, independently choose the curriculum and content, and aim to complete projects or solve problems. Therefore, this study divides the task division of STEM learning activities into three types: student-independent learning, teacher instructional guidance, and learning partners.

Personal characteristics

Different solvers have different abilities when facing the same problem, which leads to different understandings of the difficulty of the problem. The greatest difference between experts and novices in solving problems lies in the way in which knowledge is stored and retrieved in their memories. Generally, experts tend to organise knowledge in a hierarchical and categorised way for easier memory storage; on the other hand, newcomers prefer to remember knowledge in pieces (Singh, 2009). Besides intelligence factors, non-intelligence factors are also important for creativity. Several studies have confirmed that individual learning motivation can promote students' creativity (Feist, 2006; Mack,2021; Makel, 2016). One of the typical elements of internal motivation is learning interest, and one of the typical elements of external motivation is the motive to avoid failure. Therefore, personal characteristics such as previous cognitive structures, the motive to avoid failure and learning interests are selected to cultivate STEM innovative talents.

Activity objective

The goal of STEM learning activities is to foster creativity for STEM learners. As for the composition of individual creativity, although the original 1988 componential model was significantly modified, Amabile and Pratt still used the three main components of creativity in their 2016 paper. Including motivation to do creative work, skills in the task domain and creativity-relevant processes (Amabile, Pratt, 2016). Most scholars believe that creativity is the production of new ideas, products, and solutions. Hong and Song (2020) take idea creation and problem-solving as two sub-elements of creative behaviour. In addition to the dimensions of thought and ability, many studies have confirmed the key role of personality in creation, such as Conscientiousness (John, Srivastava, 1999; Amabile, 2018). However, there are also different views on this research. Ginns et al. (2014) believe that personality traits may be one of the key characteristics of creative talent. To this end, the study identified three components of STEM innovative talent: creative thinking, creative capacity, and creative personality.

1.4. The Present Study

This study aimed to extend the knowledge of CfSl by using the SEM to trace class- and individual-level antecedents' relationships with CfSl. More precisely, we examined the extent to which three class-level factors (i.e., activity tools, activity rules, and division of tasks) were associated with CfSl. We also investigated the extent to which individual-level factors (i.e., previous cognitive structure, the motive to avoid failure, learning interest) mediated the relationships between the class-level factors and CfSl. Three research questions guided this study, as follows:

1. To what extent are class-level factors (i.e., activity tools, activity rules, division of tasks) associated with CfSl?

2. To what extent are individual-level factors (i.e., previous cognitive structure, the motive to avoid failure, learning interest) associated with CfSl?

3. To what extent do individual teachers' factors mediate the relationship between school-level factors and CfSl?

This research hypothesises that all class-level factors are positively correlated with CfSl. Moreover, it has a positive effect on individual-level factors, which are positively correlated with CfSl. Hence, the hypothetical model was constructed, as shown in Figure 1.

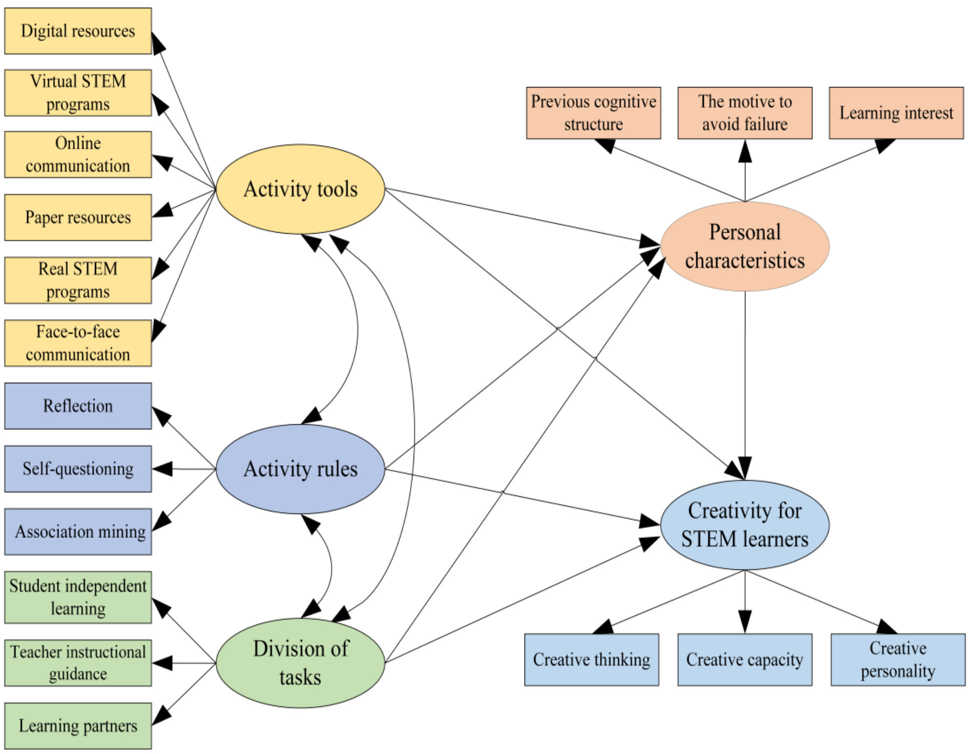

Fig. 1. Hypothesised model

2. Methods

2.1. Questionnaire Construction

A questionnaire was drafted based on the indicators from the above research model, and experts in STEM innovative talent cultivation were invited to evaluate the questionnaire indexes to ensure the rationality and effectiveness of the questionnaire structure. There were three experts: an associate professor at a university, an associate Researcher, and a research assistant at a scientific research institution. Some suggestions were given; for example, the presentation of the question was a bit abstract, which might be difficult for middle school students to understand. In addition, to increase the readability of the questionnaire, a junior high school teacher and three junior high school students were invited to read the questionnaire and make recommendations. Their suggestions included abstracting, looking tired, being unable to read, repeating words, etc.

After revision and adjustment of individual items, the final design of the questionnaire scale is shown in Table 1. What needs to be clarified is that the survey questionnaire was distributed in schools in China. The original questionnaire was presented in Chinese. It was translated into English here. Except for demographic information, all items in the survey were rated on a 5-point Likert scale, from 1 (strongly disagree) to 5 (strongly agree).

Table 1. Questionnaire outline of Factors affecting creativity for STEM students

Latent variable	Measurable variable	Strongly disagree	Disagree	Hard to define	Agree	Strongly agree
Personal characteristics	A1 previous cognitive structure	If I can organise the knowledge I have learned from different levels and disciplines, I can accurately extract the corresponding course knowledge in STEM classes.				
	A2 The motive to avoid failure	The thought of the frustration of not being able to complete my STEM assignment made me dig even harder.				
	A3 learning interest	If I am interested in STEM content, I will put more effort into my class.				
Activity tools	B1digital resources	I like to read digital learning materials on my computer or mobile phone.				
	B2 virtual STEM programs	I want STEM coursework to be done only on a computer, which is convenient and safe.				
	B3 online communication	I prefer online communication with my teachers and classmates at home rather than at school.				
	B4 paper resources	I would like to see the paper version of the research material.				
	B5 real STEM programs	I like to complete STEM courses with real work in real life; it gives me a sense of accomplishment.				
	B6 face-to-face communication	I prefer to go to school and communicate face-to-face with teachers and classmates rather than online.				
Activity rules	C1 reflection	I believe that self-reflection can help me develop innovative ideas or thoughts to complete STEM projects.				
	C2 self-questioning	Being able to ask my questions helped me think about and solve the problems I encountered in my STEM class.				
	C3 association mining	If I can relate the STEM course to the knowledge I have learned, it will help me to do my homework in the STEM course better.				
Division of tasks	D1 student independent learning	In STEM classes, I wish I could choose my own time, place, and pace of study.				
	D2 teacher instructional guidance	I hope teachers can provide the necessary guidance and help in STEM courses.				
	D3 learning partners	I want to collaborate and communicate with my classmates in the STEM class.				
Creativity for STEM learners	E1 creative thinking	In STEM classes, I always develop innovative ways to solve problems.				
	E2 creative capacity	In a STEM course, I know which material to look for or which parts of the curriculum knowledge to apply.				
	E3 creative personality	I will work hard to finish my STEM assignments and will not flinch even when faced with difficulties.				

2.2. Participants

The participants of this research were identified as Grade 8 students. The intensity sampling strategy was then applied to extract cases with high information density and intensity (Chen, 2000). As a type of purposive sampling, intensity sampling is useful in identifying cases rich with the information sought by the researcher (Sarfo et al., 2022). The sampling range was determined based on schools' recognition and implementation of STEM education. Then, within the sampling range, junior high schools A, B and C were randomly selected. Two classes of Grade 8 from each school were randomly selected as the survey subjects. These three schools are all key junior high schools in their respective regions, with a long history in STEM education. Participants' ages ranged from 13 to 15 years old, with a mean/standard deviation of 13.87±0.7284. All participants had fully equipped classrooms with STEM teaching and learning resources and teachers as part of their educational history. It was noted that they had previously achieved remarkable results in their STEM subjects. See Table 2 for details about participants' biodata.

Table 2. Participants' biodata (n = 234)

Variables	Categories	Frequency	Percentages
Gender	Female	121	51.71 %
	Male	113	48.29 %
School and Grade			
	School A -	38	16.24 %
	Grade 8	39	16.67 %
	School B -	39	16.67 %
	Grade 8	39	16.67 %
	School C -	40	17.09 %
	Grade 8	39	16.66 %

2.3. Data collection

In order to ensure the validity and reliability of the questionnaire, a small-scale test was conducted before the questionnaire was distributed. Test data showed good reliability and validity of the questionnaire scale, and formal questionnaires will continue to use this questionnaire. The questionnaire was sent to the class network group in the form of a questionnaire link (that is https://www.wjx.cn/), and the students completed it on the weekend. The questionnaire was distributed for two weeks, and 234 valid questionnaires were collected.

2.4. Data analysis

After cleaning the data of missing and invalid values, the normality of the data was tested. The absolute values of skewness of all variables are less than 1.74, and the absolute values of kurtosis of all variables are less than 3.28, which meets the recommendation. It indicates that the hypothesis of normal distribution is not seriously violated, and the distribution is moderately normal (Curran et al., 1996). The mean and standard deviation of each variable were then calculated by SPSS 25.0, and the reliability and validity were calculated. Finally, taking class-level factors as the independent variable, CfSl as the dependent variable and personal characteristics as the intermediate variable, the structural equation model was built and analysed with AMOS 28.0.

3. Results

3.1. Descriptive statistics

The descriptive statistics of each latent variable can be seen in Table 2. Among the three class-level factors, the division of tasks scored the highest (M = 4.47, SD = 0.63), followed by activity rules (M = 4.39, SD = 0.71) and activity tools (M = 3.90, SD = 0.70). It suggests that the division of tasks is more important in STEM learning, followed by activity rules and tools. The average scores for personal characteristics and CfSL were above 4.20. The correlation between variables ranges from 0.58 to 0.78.

3.2. Reliability and validity of the instrument

The internal reliability of the data was measured using CITC and Cronbach's alpha. The CITC is used to analyse the Corrected Item-Total Correlation (CITC). Generally, CITC values greater than 0.35 are considered acceptable, with values greater than 0.4 being preferable. Cronbach's alpha coefficient greater than 0.7 is acceptable. The results are shown in Table 3.

Table 2. Descriptive statistics and correlations between the latent variables (n = 234)

Variables	1	2	3	4	5
1. Personal characteristics	1				
2. Activity tools	.65**	1			
3. Activity rules	.76**	.59**	1		
4. Division of tasks	.71**	.58**	.75**	1	
5. Creativity for STEM learners	.76**	.68**	.78**	.69**	1
Mean, SD					
Mean	4.40	3.90	4.39	4.47	4.21
SD	0.68	0.70	0.71	0.63	0.75

Note: **p < .01.

Table 3. The results of the original reliability test

Latent variable	**Measurable variable**	**CITC**	**Cronbach's Alpha after Item Deletion**	**Cronbach's α**
Personal characteristics	A1 previous cognitive structure	0.782	0.773	0.864
	A2 the motive to avoid failure	0.791	0.781	
	A3 learning interest	0.699	0.859	
Activity tools	B1 digital resources	0.546	0.682	0.740
	B2 virtual STEM programs	0.632	0.652	
	B3 online communication	0.565	0.679	
	B4 paper resources	0.450	0.713	
	B5 real STEM programs	0.497	0.703	
	B6 face-to-face communication	0.201	0.763	
Activity rules	C1 reflection	0.859	0.893	0.911
	C2 self-questioning	0.890	0.829	
	C3 association mining	0.814	0.814	
Division of tasks	D1 student independent learning	0.649	0.815	0.835
	D2 teacher instructional guidance	0.748	0.737	
	D3 learning partners	0.722	0.759	
Creativity for STEM learners	E1 creative thinking	0.781	0.841	0.887
	E2 creative capacity	0.799	0.824	
	E3 creative personality	0.763	0.854	

Except for B6 face-to-face communication, it can be seen that the CITC values of other indicators are all above 0.4, and Cronbach's α value after deleting this item is smaller than the α value of the original variable. The Cronbach's α of all latent variables were all above 0.74.

The results of the reliability with the B6 removed are shown in Table 4.

Table 4. The results of the reliability test – after B6 is deleted

Latent variable	**Measurable variable**	**CITC**	**Cronbach's Alpha after Item Deletion**	**Cronbach's α**
Activity tools	B1 digital resources	0.562	0.710	0.763
	B2 virtual STEM	0.673	0.664	

	programs		
	B3 online communication	0.645	0.679
	B4 paper resources	0.397	0.762
	B5 real STEM programs	0.420	0.757

The results after further removing B4 and B5 were shown in Tables 5 and 6, respectively. All items of the scale met the requirements and had high reliability.

Table 5. The results of reliability test – after B6 and B4 are deleted

Latent variable	Measurable variable	CITC	Cronbach's Alpha after Item Deletion	Cronbach's α
Activity tools	B1 digital resources	0.612	0.680	0.762
	B2 virtual STEM programs	0.691	0.629	
	B3 online communication	0.645	0.661	
	B5 real STEM programs	0.331	0.805	

Furthermore, B4, B5 and B6 have too low CITC values, indicating a weak correlation between them and the other indicators. Therefore, these three indicators were removed, and the remaining indicators were renamed as online resources.

Table 6. The results of reliability test – after B6, B4, and B5 are deleted

Latent variable	Measurable variable	CITC	Cronbach's Alpha after Item Deletion	Cronbach's α
Activity tools	B1 digital resources	0.617	0.772	0.805
	B2 virtual STEM programs	0.709	0.673	
	B3 online communication	0.643	0.749	

Principal component analysis was used for confirmatory factor analysis. Factor rotation mode is the varimax method. Kaiser has given common measures of the Kaiser-Meyer-Olkin (KMO) Test for Sampling Adequacy: above 0.9 is very suitable, 0.8 to 0.9 is very suitable, 0.7 to 0.8 is suitable, 0.6 to 0.7 is generally adequate, 0.5 to 0.6 is not very suitable, and below 0.5 is unacceptable (Kaiser, 1974).

The extraction value of commonality shows the extent to which the extracted factor is representative of the original variable. Generally, it is accepted if the interpretability reaches 50 %. The cumulative contribution rate refers to the proportion of variation caused by all factors in the total variation, that is, the total influence of common factors on dependent variables. Generally believed, a cumulative contribution rate of 60 % is acceptable.

The KMO and Bartlett's test were performed on each variable; the results are shown in Table 7. The KMO values ranged from 0.7 to 0.8, indicating that it was suitable for factor analysis. In the principal component analysis, as shown in Table 7, the extraction value of communality of all variables was above 68 %, most of which were around 80 %. It can be considered that the extracted factors have a certain explanatory ability for each measurable variable. In the total variance explained, factors were extracted according to the criterion that the initial eigenvalue was above 1. If the cumulative contribution rate of the extracted factor reached more than 72 %, it indicates that the factor had a better explanatory ability for the variables. Thus, these findings indicated that each variable had good structural validity, and the result of factor analysis is ideal.

Table 7. The results of factor analysis

Latent variable	KMO and Bartlett's Tests				Communalities			Total Variance Explained						
		Bartlett's Test of Sphericity						Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	KMO	Appro. Chi-Square	df	Sig.		Initial	Extraction		Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Personal characteristics	.725	358.354	3	.000	A1	1.000	.818	1	2.386	79.534	79.534	2.386	79.534	79.534
					A2	1.000	.830	2	.380	12.661	92.195			
					A3	1.000	.738	3	.234	7.805	100.000			
online resources	.699	232.938	3	.000	B1	1.000	.683	1	2.167	72.244	72.244	2.167	72.244	72.244
					B2	1.000	.777	2	.486	16.211	88.455			
					B3	1.000	.708	3	.346	11.545	100.000			
Activity rules	.737	586.179	3	.000	C1	1.000	.879	1	2.628	87.584	87.584	2.628	87.584	87.584
					C2	1.000	.916	2	.254	8.455	96.039			
					C3	1.000	.832	3	.119	3.961	100			
Division of tasks	.714	292.628	3	.000	D1	1.000	.782	1	2.281	76.045	76.045	2.281	76.045	76.045
					D2	1.000	.799	2	.434	14.451	90.496			
					D3	1.000	.701	3	.285	9.504	100			
Creativity for STEM learners	.746	392.239	3	.000	E1	1.000	.817	1	2.451	81.685	81.685	2.451	81.685	81.685
					E2	1.000	.834	2	0.301	10.032	91.716			
					E3	1.000	.800	3	0.249	8.284	100			

3.3. SEM results

The Maximum Likelihood method was used to fit the model, and the standardised estimates are shown in Figure 2. The model gave good fits: CFI = 0.957, TLI = 0.943, RMSEA = 0.079 and SRMR = 0.0439, but some variables had low load and path coefficients. According to the judgment criteria of "factor load at least 0.60, standardised path at least 0.30", the variables and paths that do not meet the standards would be deleted.

After correction, the result of the modified fit is shown in Figure 3. The model fitted well: CFI = 0.958, TLI = 0.943, RMSEA = 0.094, SRMR = 0.042. The modified variable load coefficients and path coefficients satisfied the established requirements. Activity rules had significant positive effects on personal characteristics ($\beta = 0.50$, $p < 0.001$) and CfSl ($\beta = 0.44$, $p < 0.001$). Division of tasks had a significant positive effect on personal characteristics ($\beta = 0.39$, $p < 0.001$) but had no direct effect on CfSl. Compared to the division of tasks, activity rules had a larger impact on personal characteristics. Personal characteristics significantly positively affected CfSl ($\beta = 0.51$, $p<0.001$). Online resources had a weak positive effect on Personal characteristics ($\beta = 0.20$, $p < 0.001$) and CfSl($\beta = 0.12$, $p < 0.001$). Division of tasks had a weak direct effect on CfSl ($\beta = 0.11$, $p < 0.001$).

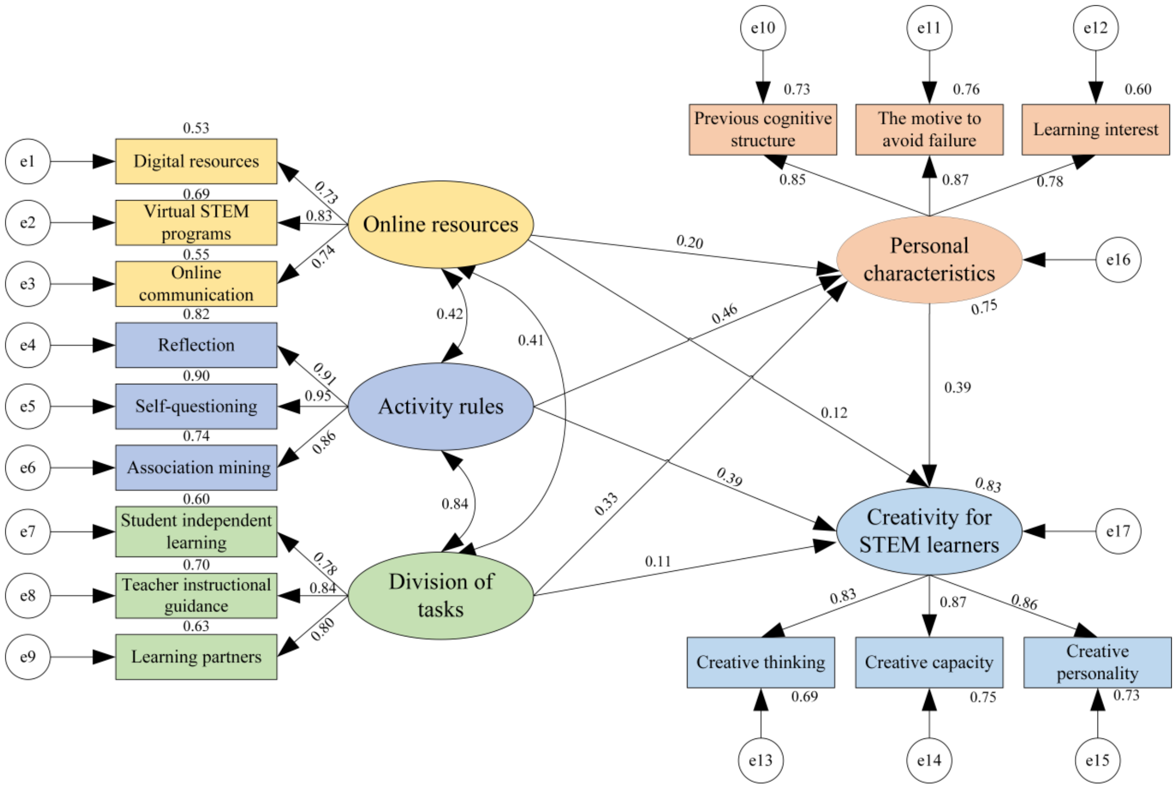

Fig. 2. The graph of normalised path coefficient – before model modification

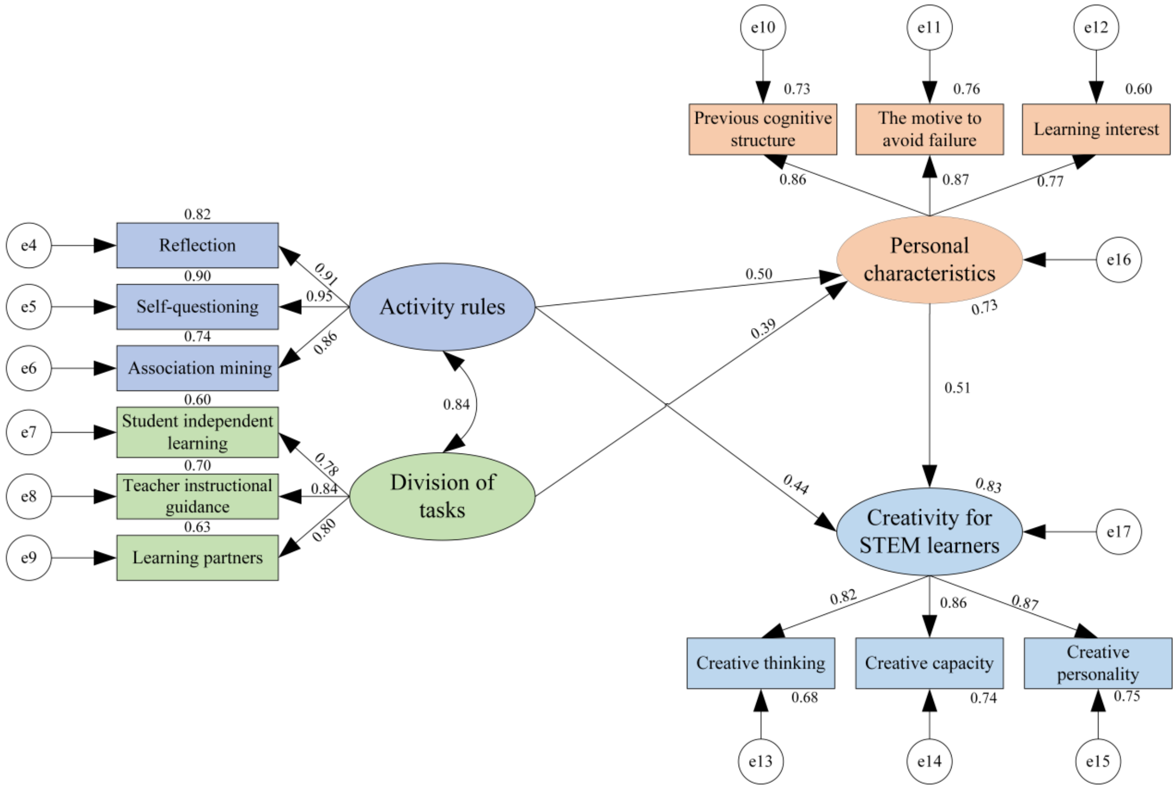

Fig. 3. The graph of normalised path coefficient – after model modification

4. Discussion

This research examined the relationships between class-level, individual-level factors, and CfSl. Found that activity rules had a stronger effect on personal characteristics compared to the division of tasks. The direct influence of the value of activity rules on personal characteristics is larger than that of CfSl. The division of tasks was mediated by personal characteristics, which indirectly positively affect CfSl, but only weakly on both personal characteristics and CfSl.

4.1. Relationships between class environments and personal characteristics

Both division of tasks and activity rules were positively correlated with personal characteristics. Among them, compared to the division of tasks (0.39), activity rules (0.50) had a greater impact on personal characteristics, as shown in Table 8.

Some studies have proved that reflection could promote students' reading, expression, analysis and other abilities (Darmawansah et al., 2022; Oo, Habók, 2022; Hsu et al., 2022). Along the way, individual characteristics of students, such as cognitive structure and learning interests, will inevitably change. Polya (1945) believed that exploring and analysing relationships between concepts could facilitate the solution of mathematical problems. The practice research of Yuriev and his colleagues also showed that students repeatedly used relationships between concepts and restructuring the problem when solving chemistry problems (Yuriev et al., 2017). Schwartz (2016) believed that children's curiosity occurred in the interval of interaction with others, and asking questions was a way of high-quality interaction between teachers and students. Questioning itself is a cognitive activity. How to raise better questions and create a zone of proximal development based on students' existing cognition was worth continuous exploration by teachers and students (Salmon et al., 2021).

The above results were consistent with the conclusions of the present study. There seems to be little research examining the value differences between cultures and divisions of labour in shaping students. This study found that compared to the division of tasks (0.39), activity rules (0.50) had a greater effect on personal characteristics, as shown in Table 8. It can be argued that the learning culture or rules created by learning cognitive activities better shape the quality characteristics of individual students compared to the function of different roles in learning. As shown in Table 8, of the three sub-elements of personal characteristics, the activity rules and the division of tasks had the greatest impact on the motive to avoid failure; second, the previous cognitive structure; and finally, the learning interest. It can be argued that emotional motivation is the most easily influenced by external circumstances, which then mobilise students to construct meaningful learning, change cognitive structures, and finally, slowly change their interest in learning a particular course.

4.2. Relationships between class environments, personal characteristics, and CfSl

Both personal characteristics and activity rules were positively correlated with CfSl. Among them, compared to personal characteristics (0.51), activity rules (0.44) had a smaller effect value on CfSl but a larger effect of total influence (the total effect value of activity rules is 0.699; The activity rule has a total effect value of 0.699; the total effect value of personal characteristics is 0.507), as shown in Table 8. As the mediating variable of activity rules and CfSl, the mediating effect size of personal characteristics was 36.48 % (indirect effect/total effect) *100 %. It showed that the direct effect of the activity rules on CfSl had a larger value than the indirect effect. The above indicated that the cultural atmosphere of learning rules was more strongly related to CfSl than the learners themselves.

Hao et al. (2016) used electroencephalography to explore the neural correlates of idea generation and reflective assessment. The results showed that participants' ideas after the reflection task were more original than those they had previously generated. They suggested that reflective evaluation may induce a high degree of internal attention or top-down activity, thus promoting effective retrieval and integration of internal memory representations and saving intellectual energy to generate new ideas. Studies proved that possible thinking could drive creativity (Chappell et al., 2008; Craft et al., 2012; Cremin et al., 2013). Questioning, as one of the characteristic features of possibility thinking, is the process of completing inquiry by continually asking and answering questions, creating conditions and opportunities for creation. In this study, a similar conclusion was obtained by means of a structural equation model. The difference was that, in this study, the cultural atmosphere of learning rules was found to be more strongly correlated with CfSl compared to individual characteristics. Division of tasks had only an indirect effect on CfSl, with an effect value of 0.196, which was low.

Moreover, of the three sub-elements of CfSl, whether personal characteristics, activity rules or division of tasks, it had the greatest influence on the cultivation of creative personality, followed by creative capacity and creative thinking, as shown in Table 8. It showed that of the three characteristics of CfSl, creative personality was the easiest to cultivate, creative capacity could be developed slowly, and only creative thinking required more time and energy. At the same time, it also showed that creative thinking was probably the most important of the three characteristics of innovative talent.

Table 8. Standardised Total Effects, Standardised Direct Effects, and Standardised Indirect Effects

Variables	Standardised Total Effects				Standardised Direct Effects				Standardised Indirect Effects			
	DOT	Activity rules	PC	CfSl	DOT	Activity rules	PC	CfSl	DOT	Activity rules	PC	CfSl
Personal characteristics	.386	.503	.000	.000	.386	.503	.000	.000	.000	.000	.000	.000
CfSl	.196	.699	.507	.000	.000	.444	.507	.000	.196	.255	.000	.000
Learning interest	.299	.389	.775	.000	.000	.000	.775	.000	.299	.389	.000	.000
The motive to avoid failure	.337	.439	.873	.000	.000	.000	.873	.000	.337	.439	.000	.000
Previous cognitive structure	.330	.430	.856	.000	.000	.000	.856	.000	.330	.430	.000	.000
creative personality	.170	.606	.440	.867	.000	.000	.000	.867	.170	.606	.440	.000
creative capacity	.168	.600	.436	.859	.000	.000	.000	.859	.168	.600	.436	.000
creative thinking	.161	.576	.418	.824	.000	.000	.000	.824	.161	.576	.418	.000
Student independent learning	.776	.000	.000	.000	.776	.000	.000	.000	.000	.000	.000	.000
Teacher instructional guidance	.836	.000	.000	.000	.836	.000	.000	.000	.000	.000	.000	.000
Learning partners	.796	.000	.000	.000	.796	.000	.000	.000	.000	.000	.000	.000
Association mining	.000	.860	.000	.000	.000	.860	.000	.000	.000	.000	.000	.000
Self-questioning	.000	.950	.000	.000	.000	.950	.000	.000	.000	.000	.000	.000
Reflection	.000	.906	.000	.000	.000	.906	.000	.000	.000	.000	.000	.000

Notes: PC = Personal characteristics; DOT = Division of tasks

5. Conclusion and implications

In the present study, SEM was used to explore the mechanism of influence of classroom and individual-level factors on CfSl. The results revealed conclusions similar to existing studies, but also extended them. This study found that of all the environmental-level factors, activity rules had the greatest impact on CfSl, even more so than personal characteristcis. This highlighted the key value of the learning rules culture in innovative learning. In addition, the study found that among personal characteristics, emotional motivation, such as the motivation to avoid failure, was most susceptible to external environment, which then mobilised students to construct meaningful learning, altered cognitive structure, and finally slowly changed their interest in learning a course. In the cultivation of innovative talent, creative personality is the easiest to cultivate, creative capacity can be developed slowly, and only creative thinking requires more time and effort.

5.1. Activity rules had the greatest influence on the cultivation of CfSl

As seen from the findings, activity rules had a stronger effect on creativity generation compared to personal characteristics. The relationship between personal characteristics and activity rules can be analogous to the relationship between self and the outside world or between humans and nature, indicating that the occurrence and operation of things should follow the natural law and combine their own characteristics. At the same time, it also brings some enlightenment to teaching.

5.2. There was a split between online and offline resources

The confirmatory factor analysis and reliability calculation results in this study decomposed the online and offline learning resources into two factors, namely online and offline resources, indicating that these two factors were independent and uncorrelated. That is, there was a strong separation between online and offline resources. The reason may be attributed to the natural "relative" characteristics of the two factors, which were similar to "reality and network", and also caused the "inherent" attribute of this separation problem. This issue posed a great challenge for integrating online and offline teaching. Since there is a strong separation between different types of resources, it is necessary to turn our attention to content and methods for the integration of online and offline teaching. The continuity and complementarity of online and offline teaching content should be ensured, and the coherence and appropriateness of the integrated approach should be ensured to eliminate as much as possible the sense of separation caused by the use of online and offline resources together.

5.3. The motive to avoid failure can stimulate the learners' desire for innovation

Of the three sub-elements of the learner, the standardised effect value of learners' motivation to avoid failure was the largest, indicating that this factor had the greatest impact on the learner's creativity, the second was the previous cognitive structure, and the last was the learning interest. It is well known that the motive to avoid failure is the motivation to avoid failure, punishment, and other external factors, and it belongs to the class of external motives. Learning interest is the motivation arising from the learner's interest in the thing itself, which belongs to the internal motives. It can be argued that external motivation better stimulates the learner's desire to innovate compared to internal motivation. Modern psychological research also showed that the persistence of internal motivation was stronger than that of external motivation, which can only be sustained on the premise of obtaining some reward or avoiding some kind of punishment (Balamoorthy, Chandra, 2023; Diwakar et al., 2023; Liu, 2020). This study hypothesised that external incentives were more stimulating in the short term but less persistent. More research is needed to confirm this. Of course, motivation is also influenced by the learner's age, subject, period of study, and many other factors. Based on these assumptions, this study suggests that in teaching, students' learning and creative aspirations may be more stimulated if teachers can give certain rewards and punishments compared to the learner's interests and preferences.

5.4. Innovative thinking maybe a core trait of CfSl

The study's findings showed that activity rules and personal characteristics had the greatest influence on the development of the creative personality, followed by the creative faculty and creative thinking. Thus, this study presents the following three perspectives:

a. Creative personality was the key characteristic of CfSl. Personality characteristics, just like human habits, can be developed through acquired perseverance, a quantitative and fundamental change in the cultivation of innovative talent.

b. Creative capacity was the characteristic of CfSl, which can be obtained after continuous training day after day. In other words, if a person has a strong creative capacity, it indicates that he has a durable and stable trait of innovation, but this trait may be temporary and one-off. Only changes in thinking are durable and long-lasting, resulting from qualitative changes followed by quantitative ones.

c. Creative thinking is the core trait of CfSl, which is the most difficult to develop. It may also be the most precious trait of STEM innovative talents, which is not easy to copy and imitate. The creative capacity of a person with creative thinking should be stable and lasting, able to output innovative results and show stable creative thinking continuously. Objective reasons such as project difficulty will not affect the thinking judgment (Azaryahu et al., 2023). It takes a long time to develop. Some implications for STEM innovation talent cultivation: the persistence of a learning character is the foundation of innovation, and only sufficient effort and knowledge can be the soil for innovation.

6. Limitations

The limitations of the present study suggest directions for future research. First of all, the questionnaire scale of this study was self-developed, and its scientificity and validity required more exploration. Secondly, this study focused on the influence of classroom and individual levels on CfSl. However, this study did not include parents and other factors (Dong et al., 2022; Li et al., 2022). Besides, the data in this study were all from questionnaires, so if supplemented by interviews, we might have a deeper understanding of the conclusions of the study. Finally, due to the academic ability of the authors, an in-depth description of the internal psychological mechanisms among the various variables was not detailed enough, which was not conducive to the understanding of the cultivation mechanism of CfSl. Therefore, future studies need to re-test the relationships between the studied variables using validated scales to confirm whether the conclusions of this study were available. Additional supporting material, such as interviews with teachers and students, should be collected to test the findings. In addition, the internal psychological logic of the inter-variable influence mechanism needed to be explored in detail to obtain more extended information about CfSl.

7. Ethics statement

All students participating in the study were informed of the purpose of the survey and the data collection process and consented to participate.

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10. Competing interests

The authors declare no competing interests.

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