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A review of research on STEM preservice teacher education (Work in Progress)

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A review of research on STEM preservice teacher education

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Abstract With the development of STEM education, various research has found that high-quality STEM teacher played an indispensable role in cultivating STEM talents. For the important role of STEM preservice teacher, it is necessary to systematically investigate the existing literature to obtain a clear understanding of the research status and trends. Based on this, systematic literature analysis was used to examine the articles that related to STEM preservice teacher education in this study. The researchers developed rigorous literature selection criteria and procedures to finally obtain 166 articles on STEM preservice teacher education which published between 2012 and 2021 from Web of Science database. CiteSpace software was used for further visualization and cluster analysis to analyze the knowledge base, research frontier, research hotspots, and research trends. Preliminary findings suggested that though the research of STEM preservice teacher education has a short history, it shows an upward trend. Although the basic theory and cutting-edge knowledge do not reflect unified conclusions, there are obvious clusters in the research hotspots, and reflect some research trends.

Keywords: STEM; preservice teacher education; CiteSpace; review

1. INTRODUCTION

Driven by technological innovation and increasingly fierce international competition, countries all over the world have sought cultivation programs for innovative talents, STEM education with innovative characteristics had emerged as required. With the continuous development of STEM education, STEM teachers were regarded to be the important factors in cultivating STEM talents [1]. Many developed countries have increased the investment in STEM education especially in STEM teacher education and formulated a series of policies and measures. For example, as early as 2011, the United States emphasized in the report of “American Innovation Strategy” that the government should pay special attention to STEM education and strived to cultivate 100,000 teachers engaged in STEM education by 2020. Besides, in 2019, the Ministry of Education of the United Kingdom issued the “Funding Manual for Preservice Teacher

Training Grants", which provides different levels of scholarships for students who participate in STEM-related preservice training courses, thus attracting a large number of graduates with STEM discipline backgrounds to become STEM teachers and voluntarily improve their teaching abilities.

With the continuous advancement of STEM education, researchers had also found that high-quality STEM teachers play an indispensable role in cultivating STEM talents [1], [2], STEM teachers arrange STEM-related courses and carry out interdisciplinary integrated teaching, which is the most direct and effective factor in improving students' STEM academic achievement effectively [3], [4]. As the STEM teacher education is playing an increasingly important role in teacher education and innovative talent cultivation, it is necessary to systematically investigate the existing literature, to have a more comprehensive and systematic understanding of STEM teacher education and provides favorable evidence for subsequent related studies.

Therefore, this study systematically reviews the articles on STEM preservice teacher education from the Web of Science database, and conducts visualization and cluster analysis on the selected articles by CiteSpace software, to analyze the main topics and hot spots of STEM preservice teacher education and provide a theoretical basis for future studies.

2. LITERATURE REVIEW

STEM (science, technology, engineering, mathematics) as an educational method began in the United States in the 1980s. In the past 30 years, STEM has received increasing attention in education, as well as in industry and even business, but still have not been able to construct a clear definition [5], [6], [7]. Various stakeholders and organizations have tried to form a recognized theoretical framework that can be constructed to reflect the interdisciplinary and integrated nature of STEM education [8], [9]. In 2001, the National Science Foundation of the United States defined STEM as: STEM should not only be a simple combination of mathematics, science, engineering, and technology, but also includes the social behavioral sciences such as psychology, economics, sociology, political science, etc. [10]. Bybee [1] defined STEM as an integrative approach to education that simultaneously combines science, technology, engineering, and mathematics disciplines with different real-life topics. With the deepening of research, more and more disciplines are integrated into STEM. In teaching, it is also found that solving a certain problem often requires multidisciplinary participation, STEM is no longer just a simple combination of the four disciplines, but emphasis more on the process of interdisciplinary learning [11]. The goal of STEM is to provide students with an integrated, interdisciplinary learning environment to better acquire and apply the knowledge and skills required in the 21st century [12].

STEM teachers are often regarded as the important factors of improving STEM education, as the STEM teachers teach students knowledge and skills and meanwhile continuously improving STEM curriculum and teaching methods, to cultivate STEM talents but also promote the development of STEM education [1], [13]. But various research also has indicated that it is not enough for STEM teachers to only have the knowledge of their own disciplines to cultivate STEM innovative talents, but also other STEM literacy to effectively teach and apply in practice and practical education [14], [15]. Yildirim and Sidekli [16] also emphasized in their research that STEM teachers need quality and effective STEM education to improve their pedagogical knowledge, situational knowledge, 21st century skills knowledge and integrated knowledge, to make them more competent at their jobs [17].

As a new teaching method, STEM education needs new courses, professional development and training plans which are suitable for the development of STEM preservice teachers [3], [18]. Based on the characteristics of interdisciplinary, interesting, and integrated of STEM education, it is far from enough for STEM teachers to have a single subject knowledge [19]. Besides their own subject, STEM teachers also need to learn other subjects relate to STEM in the preservice stage and be able to flexibly use comprehensive subject knowledge to solve practical problems [20].

Encouraging STEM preservice teachers to cultivate innovative thinking and engineering practice ability, combined with comprehensive disciplinary knowledge, can effectively promote the cultivation and improvement of STEM preservice teachers' literacy and capability [21], [22].

The current research on STEM preservice teacher education has not formed a highly unified theory and method. The research content is extensive, and the research methods are diverse. In view of the important role of STEM preservice teachers, it is necessary to systematically review and sort out the literature in this field, and analyze the research frontiers and hotspots, to provide a certain theoretical basis for future research.

3. METHODS

Existing research shows that the research on STEM preservice teacher education had a diverse trend. To clarify the current research status of STEM preservice teacher education, this research used the bibliometric analysis and content analysis methods to systematically summarize the existing literature.

The study utilized the Web of Science (WOS) as the database. The literature selection method is as follows: First, use "STEM & preservice teacher" or "STEM & pre-service teacher" as the key words to search the relevant articles. After that, set the time from 1986 to 2021, as the concept of "STEM" was first proposed in 1986 in the Neil Report. Chose the Web of Science Core Collection as the journal source, and further refine the articles in the categories of "article" and "review" and the language in English, got a total of 276 articles. Finally, systematically read the titles and abstracts of these articles, excluding those did not conform to STEM preservice teacher education. The aim of the specific criteria is to find clear information of "STEM" and "preservice teacher education" information in the title, keywords and abstract, and to read the full text of the articles that cannot find clear information in the above three parts. Finally, got 166 articles. The text is exported as a basic sample for subsequent analysis.

Bibliometric methods can present a panoramic view of the status, research areas and hot spots of research [23]. The bibliometric analysis of this paper can be divided into two parts: First is the descriptive statistical analysis, mainly depended on the data from the Web of Science database. Second is citation cluster analysis. The software for citation cluster analysis is CiteSpace. Co-citation analysis was performed on selected samples. CiteSpace is a visualization software developed by Professor Chen Chaomei using Java language. By using co-occurrence analysis, co-citation analysis and other theories to measure literatures in specific fields, it can explore the critical path of the evolution of subject fields and their knowledge inflexion points (represented by key articles). And through a series of visual atlas to explore the potential power and development frontier of the discipline fireworks, suitable for the overall comprehensive analysis.

4. FINDINGS

4.1 Descriptive statistics

Descriptive statistical analysis mainly scans the literature in the field of "STEM preservice teacher education" from the annual number of articles, high volume journals, top authors and their affiliations.

(1) Annual number of articles. Figure 1 shows that the number of articles of STEM preservice teacher education are generally on the rise, from 2 in 2012 to 49 in 2021, and showing a significant growth trend after 2016, but the whole development process is relatively short. The overall trend shows that the research on STEM preservice teacher has received sustained attention from researchers. Meanwhile, it can be predicted from the coefficient (R^2=0.979) in the figure that the number of articles on STEM preservice teachers will continue to increase in the future.

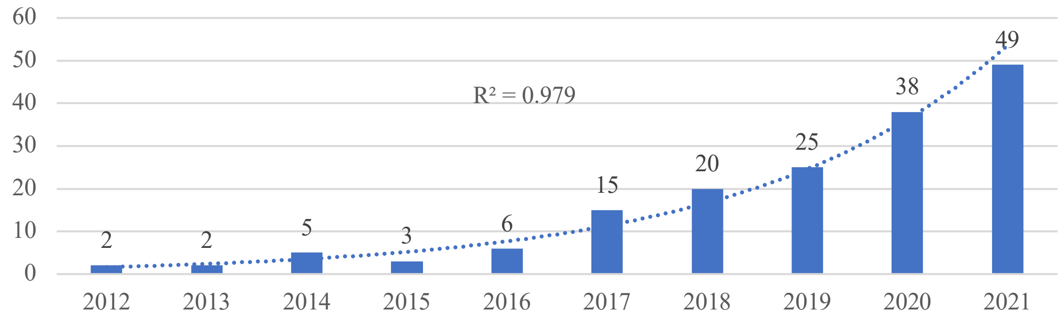

Figure 1 Annual numbers of articles on "STEM preservice teacher education"

(2) High volume journals. The statistics of journals was summarized in Table 1. Through sorting out the sample articles, it can be found that the publications are mainly concentrated in "School Science and Mathematics" (published 9), "Journal of Science Education and Technology" (published 9), "International Journal of Technology and Design Education" (published 7), "International Journal of Science and Mathematics Education" (published 5), "Frontiers in Education" (Published 5), and "International Journal of Science Education" (published 5). Most of these journals focus on issues related to science education, as well as mathematics and technology.

Table 1 High volume journals (Partial)

	Journal	No. of Articles
1	School Science and Mathematics	9
2	Journal Of Science Education and Technology	9
3	International Journal of Technology and Design Education	7
4	International Journal of Science and Mathematics Education	5
5	Frontiers in Education	5
6	International Journal of Science Education	5

(3) Top authors and their affiliations. Table 2 summarized the authors who have published more than three articles on STEM preservice teacher education. The top four authors are Blackley S, Aydin-gunbatar S, Sheffield R and Radloff J. They have published four or more articles that were related to STEM preservice teacher education. From the analysis of these authors' affiliations and countries, there is an obvious

phenomenon of cooperation between the authors of the same university or country, especially Curtin University. STEM pre-service teacher education is a relatively new field, but some trends are beginning to emerge, there is a great space and potential for researchers.

Table 2 Top authors and their affiliations

	Author	No. of Articles	Institution/Country	Total Citations
1	Blackley S	5	Curtin University, Australia	43
2	Aydin-gunbatar S	4	Yuzuncu Yil University, Turkey	12
3	Sheffield R	4	Curtin University, Australia	40
4	Radloff J	4	SUNY Cortland, USA	33
5	Ekiz-kiran B	3	Gaziosmanpasa University, Turkey; Yuzuncu Yil University, Turkey	12
6	Gonzalez-gomez D	3	Universidad de Extremadura, Spain	10
7	Jeong JS	3	Universidad de Extremadura, Spain	10
8	Koul R	3	Curtin University, Australia	40
9	Lin KY	3	National Taiwan Normal University, China	17

4.2 Citation Cluster Analysis

This study focuses on the importance and necessity of STEM preservice teacher education, and it is expected to clarify the key information such as the research basis and hot spots in this field by sorting out and analyzing the existing literature, to provide a literature basis for subsequent studies. Therefore, CiteSpace visualization software was used in this study to draw and quantitatively analyze the visualization atlas of the 166 sample literatures, to obtain the key literatures, keyword co-occurrence map and time zone map of STEM preservice teacher education in recent 10 years were obtained, and the key information of STEM preservice teacher education research field such as research basis and research hotspots was summarized in the following analysis.

(1) Node types: Cited reference. “Cited reference” is selected as the node types to analyze the knowledge base and research frontier of STEM preservice teacher

education. The knowledge base is composed of the collection of co-cited literatures, while the research frontier is composed of the collection of cited literatures that cite these knowledge bases. The following Table 3 summarized the most highly co-cited articles (top 10), and Figure 2 Figure 2 shows a visualization of these co-cited articles. These highly co-cited literatures are widely recognized theories and knowledge bases in STEM preservice teacher education and are highly recognized.

Table 3 The most highly co-cited articles (Top 10)

	Title	Author	Year	Count
1	NGSS Lead States. 2013. Next Generation Science Standards: For states, by states. Washington, DC: National Academies Press.		2013	23
2	The case for STEM education: Challenges and opportunities	Bybee, R. W	2013	14
3	A concptual Framework for Integrated STEM	Kelley, T. R.	2016	12
4	Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers	Nadelson, L. S., et al.	2013	11
5	STEM education K-12: Perspectives on integration	English, L. D.	2016	10
6	STEM integration in K-12 education: Status, prospects, and an agenda for research	National Research Council	2014	9
7	Characterizing STEM Teacher Education: Affordances and Constraints of Explicit STEM Preparation for Elementary Teachers	Rinke C. R.	2016	8
8	Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching	Kim, C., et al.	2015	7
9	What is STEM? A discussion about conceptions of STEM in education and partnerships	Breiner, J. M., et al.	2012	7
10	Introducing STEM education: Implications for educating our teachers in the age of innovation	Corlu M. S.	2014	7

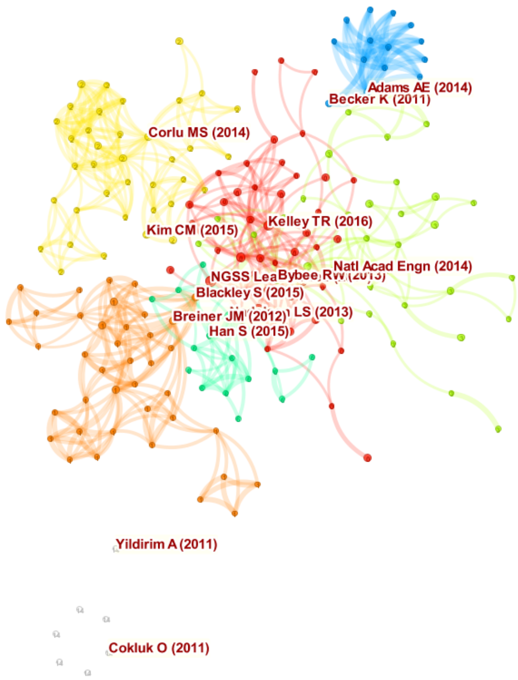

Figure 2 The highly co-cited articles

The cluster naming of cited reference can be considered as the frontier of research, which is mainly determined by the nominal words extracted from cited literature. Using the title words the cluster the co-cited references, the results are showing in the following Figure 3. The results show that the research frontiers of STEM preservice teacher education can be summarized as into seven aspects, including pre-service chemistry teacher, STEM education, pre-service science teacher, mathematics education, pre-service teacher perception, robotics, powerful teacher education. Most of the frontier research focused on the education of single-subject (especially chemistry, science, and mathematics) preservice teachers and the combination of robotics. But the results also showed that some scholars began to pay attention to the perception of STEM preservice teachers. But to dissect and embody the integrated and interdisciplinary of STEM education, there is still much room for development in the future.

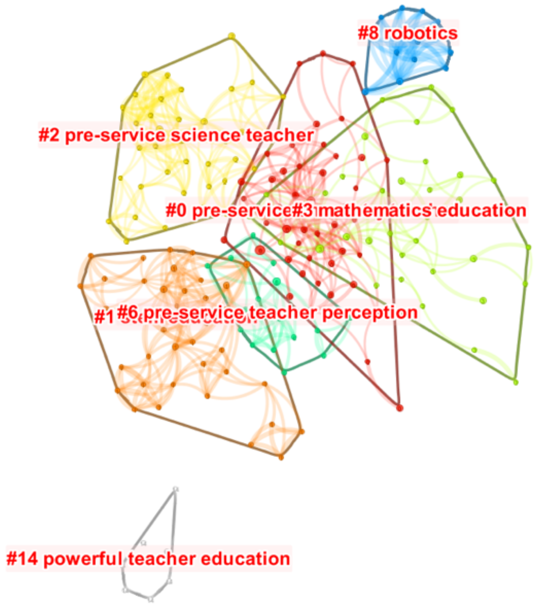

Figure 3 Citation clustering results

(2) Node types: keyword. "Keyword" is selected as the node types to analyze the research hotspots and trends of STEM preservice teacher education, and the mining analysis of co-words is mainly carried out on the main body of the literature. Through co-word analysis, some topics of common concern to scholars in this field can be further inferred, and the research hotspots in this field can be obtained from the time, frequency, and length of time of the words.

The co-words (count > 5) in cited articles are summarized in the following Table 4 and Figure 4, including preservice teacher, education, STEM education, belief, science, teacher education, knowledge and so on. Co-words can also be considered as hot keywords, which are the summary of the core content of existing literature. The analysis of defective co-words can reflect the research hot spots in STEM preservice teacher education. The results of Table 4 show that, apart from the usual words such as "STEM education", "pre-service teacher" and "teacher education", science is a major research hotspot, which appeared in 2015 and 2017 and lasted for a long time. Others, such as mathematics was the hot topic around 2015, while technology was in 2020.

In addition, the research hotspots in the recent five years (2017-2021) also included self-efficacy, thinking especially computational thinking, achievement, and classroom. Based on previous studies, researchers in recent years have focused on the self-efficacy of STEM pre-service teachers as influencing their intention to choose STEM careers in the later period. Besides, some scholars believed that the rapid development of information technology and computing machines can effectively promote the practice and realization of concepts and ideas, so it is very important to strengthen the computational thinking of STEM preservice teachers. In addition to the theoretical knowledge education of STEM preservice teachers, researchers have also paid attention to their practical teaching capability and classroom design to make sure students' learning outcomes. This practical research provided a variety of successful teaching and curriculum design cases for STEM teacher education.

Table 4 Summary of the co-words (count > 5)

	Keywords	Year	Count		Keywords	Year	Count
1	Education	2012	41	17	Pedagogical content knowledge	2018	10
2	STEM education	2015	29	18	Impact	2012	10
3	Science	2015	28	19	Self-efficacy	2017	10
4	Preservice teacher	2012	24	20	Science education	2017	8
5	Knowledge	2012	20	21	Perception	2019	8
6	Pre-service teacher	2013	19	22	Computational thinking	2017	8
7	Student	2014	18	23	Conception	2015	7
8	Teacher education	2013	18	24	Achievement	2018	7
9	Belief	2014	17	25	School	2014	6
10	Mathematics	2015	14	26	Preservice	2014	6
11	Professional development	2015	13	27	Ability	2015	5
12	Attitude	2012	13	28	Thinking	2021	5
13	Technology	2020	13	29	Model	2012	5
14	Inquiry	2014	12	30	Classroom	2017	5
15	Framework	2012	11	31	Implementation	2015	5
16	Design	2016	10				

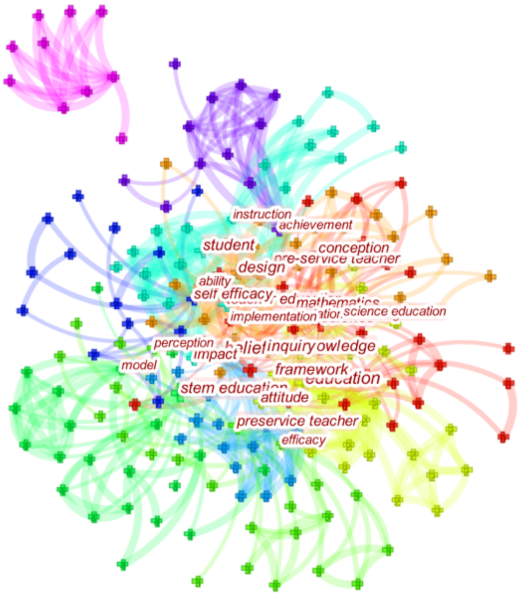

Figure 4 The co-words analysis results

Co-word analysis mainly extracts nominal terms from titles, keywords and supplementary keywords in databases to analyze the relationship between authors and research. Co-word clustering results are generally considered to show the hot topics in the related field. The analysis of Figure 5 shows that the research hotspots in the field of “STEM preservice teacher” can be clustered, mainly divided into 10 categories, including: pedagogical practice, block-based programming, socio-scientific issue, phenomenological study, using public museum collection, traditional inquiry-based science unit, preservice science teacher, responsive instruction, undergraduate STEM teacher preparation program, mathematics experience. It shows that although STEM and STEM preservice teacher education have not formed a highly unified consensus at the level of research basic and cutting-edge knowledge, researchers are still paying attention to some common topics to make useful contributions to STEM preservice teacher education.

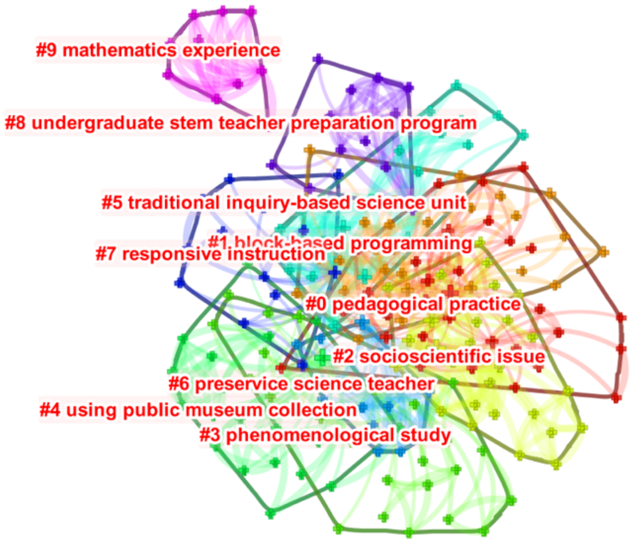

Figure 5 Cluster analysis of the keywords and terms

5. CONCLUSIONS

In view of the important role of STEM teachers in STEM education, it is necessary to systematically sort out the current research on STEM preservice teacher education, to provide a corresponding literature basis for future research. In this context, this study sorted and analyzed the articles related to STEM preservice teacher education in the Web of Science Core Collection database from 2012 to 2021, to obtain the basic information in STEM preservice teacher education field, including the annual numbers of articles, high volume journals, top authors and their affiliations. And then the researchers used the CiteSpace software to further obtain the research clusters to analyze the knowledge base, research frontier and research hotspot in STEM preservice teacher education field through different forms of clustering, to provide literature support and knowledge basis for later research. From the data and analysis results, it can be concluded that the research on STEM preservice teacher education has shown a trend of vigorous development overall, which also pushes forward from macro policies and training programs to micro aspects, such as curriculum design and teacher perception and capability training. The main conclusions are as follows:

First, through the descriptive analysis of the basic information from the Web of Science Core Collection database, it can be concluded that the research on STEM preservice teacher education began as early as 2012, but the overall development process is short, only about 10 years. The research mainly appeared after 2016 and entered a stage of rapid development from 2017 to 2021, which means the STEM preservice teacher education have received continuous attention from the researchers. The number of achievements on STEM preservice teacher education is not large but shows an upward trend.

Second, the clustering results of the cited references showed that the research frontiers of STEM preservice teacher education can be summarized into seven aspects: pre-service chemistry teacher, STEM education, pre-service science teacher, mathematics education, pre-service teacher perception, robotics, and powerful teacher education. The clustering results indicated that the research frontier of STEM preservice teacher education is still scattered, focusing more on the preservice teacher training of single subject, and less reflecting the integration and interdisciplinary nature of STEM education.

Third, form the analysis of co-words, it can be concluded that scholars have begun to pay attention to STEM preservice teachers' curriculum design and classroom practice, and pay more attention to the development of preservice teachers' personal abilities, such as self-efficacy and computational thinking in recent years. There is a degree of integration at the object level, STEM preservice teachers are studied as a whole, rather than strictly differentiated by subject. At the level of research content, the exploration of training objectives, programs and models has been transferred to the more microscopic aspects of classroom content and personal ability training.

Forth, the cluster results of keyword showed that despite the diversity and inconsistency of basic knowledge and theories, researchers still pay attention to some common problems in STEM preservice teacher education, and the main hot issues are pedagogical practice, block-based programming, socio-scientific issue, phenomenological study, using public museum collection, traditional inquiry-based science unit, preservice science teacher, responsive instruction, undergraduate STEM teacher preparation program, mathematics experience etc. The cluster results indicated that the existing articles studied more on the important role of STEM preservice teacher education in solving social-scientific problems and the cultivation of STEM pre-service teachers, but at the same time, the research also tried to push forward to a more micro level, including the improvement and practice of curriculum, as well as some research on the individual level of STEM preservice teachers.

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