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# Interrelatedness patterns of knowledge representation in extension concept mapping

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## Abstract

Extension concept mapping enhances existing maps by integrating new knowledge, yielding an additional map. This study focuses on two potential extension designs: Extended Kit-Build and Extended Scratch-Build methods. While prior research favored Extended Kit-Build for cognitive knowledge comprehension and map scores, it lacked insights into concept map-relatedness patterns. The tight connections among knowledge representations demonstrate a remarkable level of expertise and the profoundness of an individual's understanding. This study reveals interrelatedness patterns in extension concept mapping activities that connect previous and new knowledge. The dataset was obtained from a database that accommodates the results of concept mapping activities of 55 university students on two material topics. The study employed a two-group design, wherein the experimental cohort embraced the Extended Kit-Build approach, contrasting with the control cohort's utilization of the Extended Scratch-Build approach. Extension Relationship scores were utilized to evaluate the knowledge interrelatedness patterns in extension concept mapping. The scoring method assessed both the number and quality of concept map proposition relationships. The experimental group established a statistically more significant quantity and qualitative strength of extension relationships than those within the control group. In the experimental group, a statistically noteworthy positive correlation emerged between the scores of extension relationships and students' comprehension.

**Keywords:** Extension concept mapping, Interrelatedness patterns, Original map, Additional map, Extension relationships

## Introduction

Concept maps, with their visual representation of relationships between key ideas, serve as valuable tools for revealing and building an individual's understanding of complex subjects. The concept map comprises interlinked ideas, creating meaningful statements identified as propositions (Cañas & Novak, 2008; Eshuis et al., 2022). The concept map's essential



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building blocks are propositions, the smallest semantic entities. Therefore, the meaning of a concept remains incomplete unless it is interconnected with other concepts in some form or manner. The set of propositions describes the individual's knowledge of a particular topic (Kim, 2013; Wang et al., 2017). Concept maps are promising student-centered learning strategies that support the development of 21st-century skills (Deepa et al., 2022; Hu & Hwang, 2024; Prasetya et al., 2022). Concept maps have enjoyed extensive application in the educational domain, demonstrating efficacy in supporting teaching, learning, and assessment practices.

Two methods that could be used for crafting a concept map are open-ended (also known as low-directed) and closed-ended (also known as high-directed) techniques (Hirashima, 2019; Hu & Hwang, 2024; Joshi et al., 2022; Prasetya et al., 2022; Taricani & Clariana, 2006). The open-ended technique asks learners to express their understanding of particular learning materials in a blank work area, so it is also often called the scratch-build method. In the closed-ended approach, learners are provided with concepts and link components that have yet to be connected, and they are asked to reconstruct them according to the related material. The open-ended procedure offers a robust platform for uncovering student differences with high fidelity, facilitating critical thinking, and inspiring creativity (De Ries et al., 2022; Hu & Hwang, 2024; Prasetya et al., 2022; Ruiz-Primo et al., 2001), while the closed-ended method is considered effective in improving learners' understanding, deliver automated evaluation, and promptly offer feedback (Dettbarn et al., 2023; Hirashima et al., 2015; Prasetya et al., 2022; Ruiz-Primo et al., 2001).

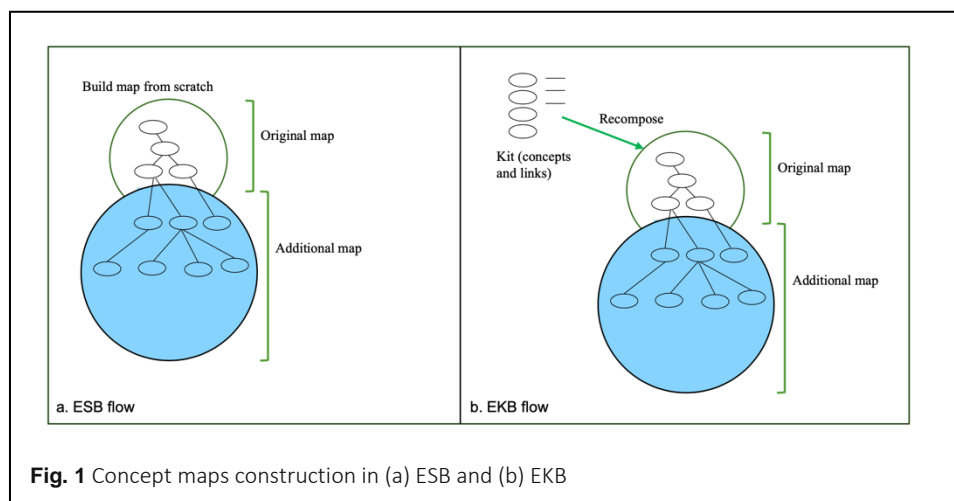
A number of concept mapping approaches, including extended concept mapping, have been suggested to meet the needs of learners better and increase their performance. The idea underlying the extended concept map is to furnish students with the chance to review their understanding to produce a more in-depth structure (Prasetya et al., 2022; Schwendimann & Linn, 2016). The extended concept map design effectively streams scheming work and creates a robust knowledge base (Foley et al., 2018). Extension concept mapping supplies associated activities for effectively arranging the expansion structure (Boffey et al., 2010; Subramanian et al., 2022) and improving problem-solving. The extended mapping activity helps students improve the prior map and correlate it with additional relevant information to increase meaningful learning.

Prior investigations have examined the potential improvement in students' academic performance through the implementation of Extended Kit-Build (EKB) and comparable designs, Extended Scratch-Build (ESB) concept maps (Prasetya et al., 2022). In ESB, the teacher invites learners to expand the open-ended concept map that was created previously using the same technique. Conversely, the EKB concept map utilizes a pre-structured Kit-Build (KB) framework while seamlessly integrating the low-directed approach into a unified process for extending the concept mapping experience. KB concept maps help

students learn and understand a topic by providing them with a pre-deconstructed concept map and asking them to reconstruct it (Andoko et al., 2020; Hirashima, 2019; Pinandito et al., 2021). EKB and ESB promote rich and meaningful learning experiences by fostering tight connections between the initial reference map and the newly constructed additional map. Figure 1 visually depicts the concept map expansion undertaken in (a) ESB and (b) EKB.

ESB aims to broaden and deepen students' understanding of a topic by promoting independence and encouraging creativity. Meanwhile, EKB emphasizes a more structured understanding of knowledge and facilitates automatic feedback and scoring. The initial investigation elucidates that, in contrast to the ESB technique, the EKB approach yields higher levels of student comprehension and concept map scores (Prasetya et al., 2021; Prasetya et al., 2022). However, previous studies did not summarize the degree of relationship pattern between the initial map and additional maps in the expanded concept map.

The fundamental aspect of cognitive knowledge lies in the inherent interrelationship between concepts (Hannell-Pamment, 2024; Schwendimann, 2015; Xu, 2022). It describes the degree of causality between the two ideas. Concept maps with a highly interrelated structure illustrate a deep knowledge of the domain or subject, as they demonstrate the ability to identify, understand, and express the intricate connections between ideas (Atapattu et al., 2017; Ruiz-Primo & Shavelson, 1996). In reality, experts develop densely interwoven maps, whereas beginners frequently produce simplistic structures (Vanides et al., 2005). Concept interrelatedness is, therefore, a key characteristic of personal knowledge. Students who have deeply ingrained knowledge structures are better able to retain material and produce significant and meaningful learning results (Kilic & Cakmak, 2013; Turns et al., 2000). It is acknowledged that the most critical aspect of



creating strong knowledge structures is meaningful learning (Eshuis et al., 2022; Novak, 2010; Novak & Cañas, 2008; Weinerth et al., 2014).

This study offers a new contribution by investigating the effect of EKB and ESB approaches on the student's capability to communicate previous and new knowledge. This research focuses on revealing interrelatedness patterns of knowledge representation in both techniques. Extension relationship (ER) scores evaluated students' cognitive structure's tightness. This study also explores the impact of acquiring ER on students' comprehension. This research delves into the patterns and effects of knowledge linkages established during concept map extension, as guided by the following two key inquiries:

RQ1: How do the patterns of knowledge interrelatedness differ between concept maps generated through the ESB and EKB approaches?

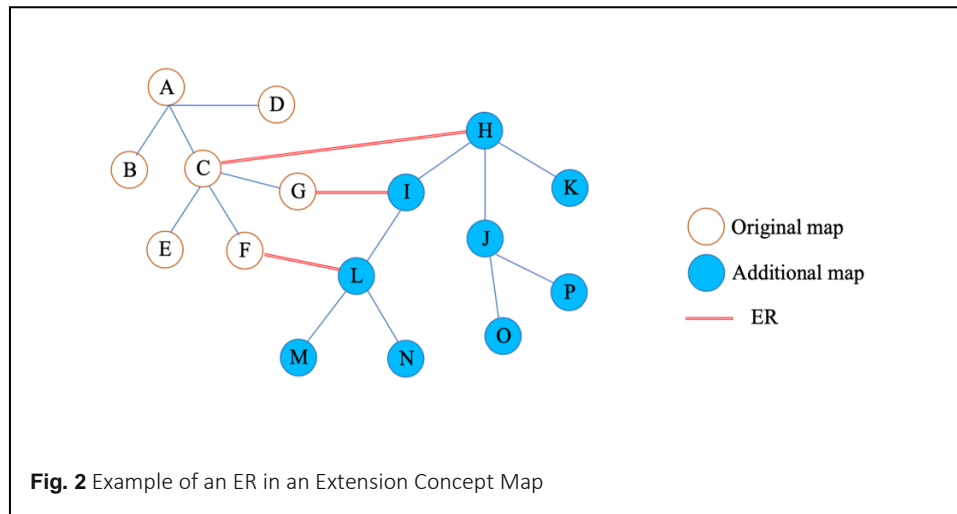
RQ2: How do ER scores affect students' comprehension test scores?

### **Interrelatedness in extension concept mapping**

The extension concept mapping technique builds upon an established concept map, progressively enriching it with novel elements tailored to the particular knowledge domain. This method entails two interconnected activities instead of standard concept maps, whose activities are finished in a single session. After gathering the first learning materials, learners are required to create the first concept map, the original map. Following exposure to the second resource, students complete the following task, which asks them to expand the first map by including fresh elements and creating further maps. Building a solid knowledge base and efficiently organizing design work benefit the extension map design (Foley et al., 2018).

Previous studies introduced ESB, which expands the open-ended technique with the same approach (Prasetya et al., 2022). In Phase 1, students are required to use an open-ended approach to develop a concept map that conforms with the initial material. According to their comprehension, students are free to contribute concepts, linkages, and definitions to the material. Students will also add new ideas, connections, and proposals to the initial concept map in Phase 2 and link them to the earlier concept map. Further extension-based concept map design recommended EKB tools that provide two mapping task stages. In Phase 1, the EKB employs the reconstruction method proposed by the KB system. Next, Phase 2 EKB is comparable to ESB in that both involve expanding the prior map by adding additional elements.

Extension relationships (ER) show how previous and new knowledge are related to one another. It depicts a relation that connects tightly between prior maps (original maps) and extended maps (additional maps). Therefore, ER presents a valuable tool for validating the enhanced depth of meaningful learning facilitated by extended concept mapping activities. Figure 2 exemplifies its application in this context. According to Ruiz-Primo and



Shavelson (1996), a key characteristic of meaningful knowledge is its integration into robust interconnected concepts within its specific domain. Individuals exposed to tightly integrated knowledge frameworks are likelier to remember information and learn meaningfully (Turns et al., 2000). ER indicates that students can increase meaningful learning by gaining new knowledge and resolving challenging problems rather than simply applying previously learned information to develop concept maps.

## Methods

### Data collection

The current study utilizes a pre-existing dataset of extension concept mapping activities conducted by Prasetya et al. (2022). This dataset consists of original map relationships and additional maps created by 55 undergraduate students in their sophomore year from informatics engineering classes. Notably, all participants were novices to concept mapping tools in their daily activities. The participants were randomly allocated into two cohorts: the control group ( $n = 27$ ) employed the ESB strategy, whereas the experimental group ( $n = 28$ ) adopted the EKB approach. An initial homogeneity examination indicated no statistically significant differences in initial knowledge between the two groups ( $p = 0.389 > 0.05$ ). Furthermore, this study leverages post-test comprehension scores from previous research for further analysis.

### Context material

The research was conducted for two consecutive weeks and involved the topics of relational databases and structured query language (SQL) in database courses. The reason for determining the implementation for two sequential times was likely to strengthen the

results of the research findings further. Each topic was subdivided into two sub-sections, prompting the generation of two interconnected concept maps. The time allotted for constructing each concept map was restricted to 15 minutes. Throughout this process, participants retained access to the distributed materials provided as reference handouts.

During the initial concept map creation in the first experiment, the control group generated 244 propositions ( $AVG = 9.04$ ;  $SD = 3.38$ ), while the additional map was 275 propositions ( $AVG = 10.19$ ;  $SD = 2.97$ ). Meanwhile, the experimental group produced an original map of 280 propositions ( $AVG = 10$ ;  $SD = 0$ ), while the additional map was 396 propositions ( $AVG = 14.14$ ;  $SD = 4.93$ ). During the SQL-focused portion of the second experiment, the control group produced 285 propositions ( $AVG = 10.56$ ;  $SD = 3.98$ ) in the original map and 326 propositions ( $AVG = 12.07$ ;  $SD = 2.53$ ) in the additional map. The experimental group had 392 propositions ( $AVG = 14$ ;  $SD = 0$ ) in the original map and 432 propositions ( $AVG = 15.43$ ;  $SD = 3.89$ ) in the additional map.

### **Instruments**

ER scores were used to determine relationships' breadth and quality in extended mapping activities. In principle, the ER is a proposition connecting the first and second maps. Proposition scoring on the concept map is recognized as an accurate measurement method (Kinchin, 2014; Kinchin et al., 2019; Prasetya et al., 2022). Propositions are crucial because they describe the vital and smallest unit of concept maps representing learners' understanding. Evaluating a proposition's correctness is considered a crucial and suggested assessment in appraising concept mapping (Bergan-Roller et al., 2020; He et al., 2023; Raud et al., 2016). Concept map assessment based on the proposition has been recognized as producing better reliability than other map component analyses (Ghani et al., 2017; Srivastava et al., 2021; Stoddart et al., 2000). The number of ERs and the quality of ERs were the two metrics for scoring ERs.

Extension Relationships (ERs) calculation involves assessing the connections that directly link concepts between the original and additional maps. The ER count reflects the number of propositions acting as intermediaries in mapping activities, providing insights into the depth of a student's understanding of a particular subject (Jaafarpour et al., 2016; Stoddart, 2006). ER serves as a measure to evaluate the breadth and depth of students' knowledge frameworks throughout extended learning activities. The ratio between the ER number and map sizes was not considered due to the equal volume of material in both groups.

The lecturer formulated the ER's quality score to assess the depth of students' comprehension. A four-level rating system was developed, with 0 denoting inaccurate, 1 representing slightly incorrect, 2 denoting correct but with a limited understanding of science, and 3 denoting scientifically valid. The same instructor manually evaluated the

quality ratings for both groups. The post-test score was used further to investigate whether there is a relationship between students' understanding and the ER score.

### Data analysis

This study predominantly relies on information gathered from 55 participants segregated into two specific cohorts: experimental and control groups. The data analysis included assessing the number and quality of ERs and post-test results. Descriptive statistical methods were employed to summarize the data obtained from the interventions administered to both groups. Considering deviations from normal distribution assumptions and the relatively small sample size, a non-parametric statistical test was conducted.

A comparative analysis of mean achievements between the control and experimental cohorts was undertaken utilizing the Mann-Whitney U test. Pearson's  $r$  was employed as a measure to evaluate the effect size (ES), with  $r$ -values falling into categories of 0.1 (small), 0.3 (medium), or 0.5 (large). Furthermore, Spearman's rank-order correlation coefficient ( $r_s$ ) was applied to reveal the univariate relationships among academic outcomes. In all these analyses, statistical significance was asserted for  $p$ -values below 0.05.

## Results

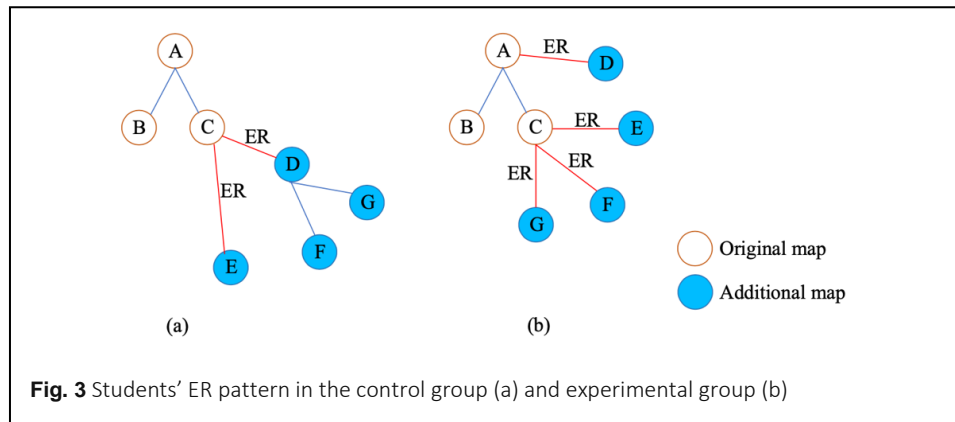
### Pattern analysis of ER NUMBER

The number of ERs is one of the measurements used to respond to the first research question. Counting the number of ERs reveals the ability of individuals to identify the number of relations in the map expansion. The amount of ER represents the group's performance in expanding the concept map components. Table 1 presents comprehensive statistics regarding the attainment of ER numbers during the initial and subsequent experiments.

During the initial experiment, the control group exhibited a maximum of two propositions directly connected to the original concept map. In contrast, participants in the experimental group could articulate up to 11 propositions. The average ER number performance of learners in the experimental group exceeded that of the control group, with scores of 5.32 instead of 1.44. The second experiment, involving a different subject matter, corroborated

**Table 1** Attainment of ER numbers in both groups

Experiment	Group	N	Min	Max	Median	Mean	SD
First experiment	Control group	27	1	2	1.00	1.44	0.51
	Experimental group	28	2	11	4.00	5.32	3.10
Second experiment	Control group	27	2	11	5.00	5.33	2.37
	Experimental group	28	4	14	7.00	7.82	2.36

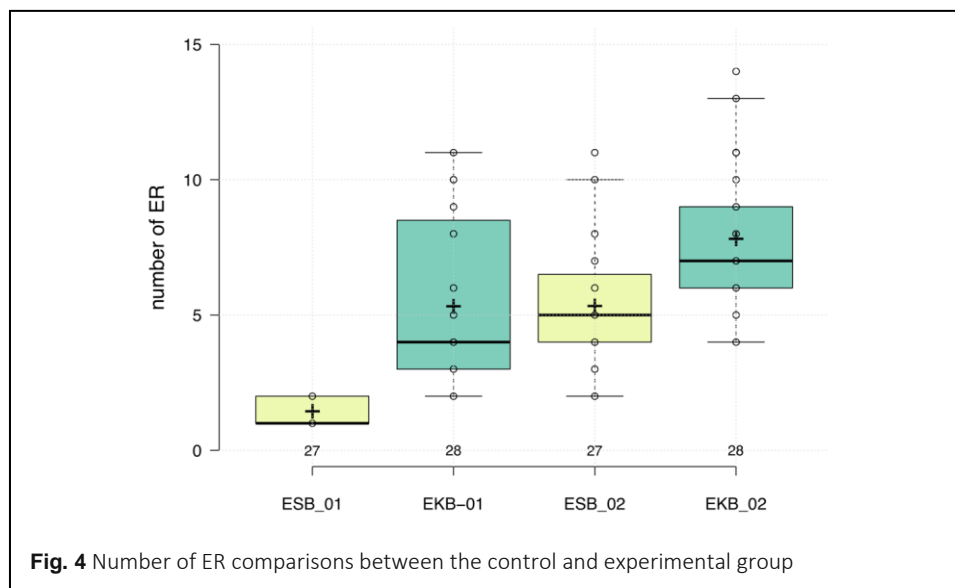


**Fig. 3** Students' ER pattern in the control group (a) and experimental group (b)

the consistent performance of students using the EKB approach. Descriptive statistics reveal that students utilizing the EKB approach excelled in all aspects. The mean attainment of students in the experimental group attained 7.82 connections, whereas the control group achieved an average of 5.33 relations.

The application of distinct concept mapping techniques provides different results. Students in both groups are indeed equally able to expand their concept maps, but in a fashion that tends to be different. The pattern of map expansion in the control group was through intermediary relations, as shown in Figure 3(a). They tend to define slight propositions, then new concepts are linked to this intermediary proposition. Different conditions were found in the experimental group that links new ideas straight to the prior original map, as presented in Figure 3(b). Expanding maps with patterns in the experimental group could define more ERs.

Figure 4 illustrates the boxplot representing the count of ERs for both groups across all experiments. In the first experiment, the achievement of the minimum and maximum



**Fig. 4** Number of ER comparisons between the control and experimental group



**Table 2** The Mann-Whitney U results of the number of ERs for both groups

Experiment	Group	Mean Rank	<i>U</i>	<i>Z</i>	<i>p</i>	<i>r</i>
First experiment	Control group	14.89	24.000	-6.113	.000	-.824
	Experimental group	40.64				
Second experiment	Control group	19.81	157.000	-3.747	.001	-.505
	Experimental group	35.89				

scores in the control group was in a low category. The interquartile range (25-75%) stated a small value, which means dominant at a low score. Different conditions were found in the experimental group, where the achievements of Q1 and Q3 were higher. Similar patterns of achievement were observed in the results of the second investigation.

Table 2 presents the outcomes of the Mann-Whitney U test aimed at discerning variations in the ER number. The initial experiment revealed a highly significant difference in both groups ( $p = .000 < .05$ ). The experimental group showcases a heightened average ER score ranking when juxtaposed with the control group. The initial experiment resulted in noteworthy discoveries, with Pearson's correlation coefficient of -0.824.

The quantity of ERs observed in the experimental and control groups differed significantly in the second experiment ( $p = .001 < .05$ ). The control group achieved a lower average rank than the experimental group. The computation of Pearson's correlation coefficient, which yielded a value of -0.505, suggested a significant effect size concerning the number of ERs.

### Pattern analysis of ER quality

The second instrument was used to confirm the first research question, which is the ER quality pattern. Similar to an ER number analysis, the evaluation considers the same relationships but was assessed using the rubric of quality of propositions. However, many propositions do not always indicate the high quality of a concept map. Table 3 presents statistical data representing the quality of ER in both the initial and subsequent experiments for each group.

The first experiment showed an accomplishment similar to the measurement of ER size. The experimental group demonstrated consistent outperformance across the full range of

**Table 3** Attainment of ER quality in both groups

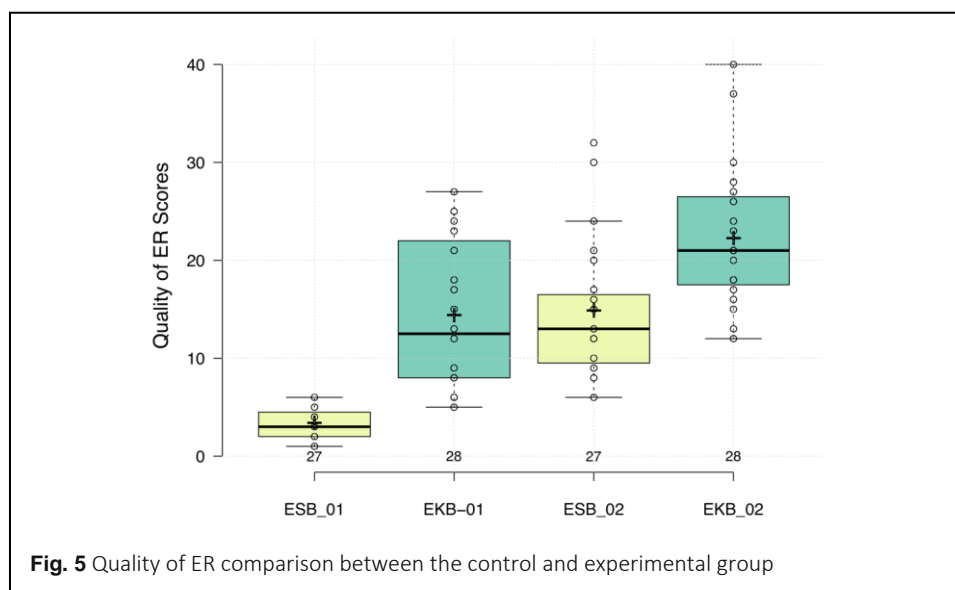
Experiment	Group	N	Min	Max	Median	Mean	SD
First experiment	Control group	27	1	6	3.00	3.41	1.50
	Experimental group	28	5	27	12.50	14.43	7.54
Second experiment	Control group	27	6	32	13.00	14.89	7.23
	Experimental group	28	12	40	21.00	22.29	6.80

performance metrics, as evidenced by their higher minimum, maximum, and median values than the control group. The average quality of ER scores of students who used the EKB approach also exceeded the control group, which was 14.43 compared to 3.41. The significant difference in the achievement of the quality of ER values was influenced by the pattern of ER definitions in the two groups.

Comparable achievements were observed in the second experiment using distinct materials, wherein participants in the experimental group consistently upheld their performances. This was demonstrated by the experimental group students outperforming the control group on all items. The average score for students in the control group stood at 14.89, while the experimental cohort secured a commendable score of 22.29.

Figure 5 illustrates a pattern of comparing the quality of ERs between both groups in the initial and subsequent experiments. In general, the accomplishments of both groups exhibited a direct correlation with the outcomes of the ER number. Students in the experimental group consistently attained high-quality ER scores throughout all conducted experiments. The lower, middle, and upper quartile values in the EKB group surpassed those of the ESB group.

The Mann-Whitney U test was utilized in the examination to determine whether there was a significant difference in the quality of ER, as shown in Table 4. The preliminary study results revealed significant differences ( $p = .000 < .05$ ) between the two groups, supported by a Pearson's  $r$  of -8.32, which suggests a considerable effect size. Similarly, in the subsequent experiment, significant differences in the quality of ER scores were observed between the two groups ( $p = .001 < .05$ ). The significant effect magnitude was highlighted by Pearson's  $r$ , which recorded a value of -5.515.



**Table 4** The Mann-Whitney U results of the quality of ER for both groups

Experiment	Group	Mean Rank	<i>U</i>	<i>Z</i>	<i>p</i>	<i>r</i>
First experiment	Control group	14.50	13.500	-6.169	.000	-.832
	Experimental group	41.02				
Second experiment	Control group	19.61	151.500	-3.822	.001	-.515
	Experimental group	36.09				

The EKB approach demonstrably enhanced students' learning outcomes, as the Mann-Whitney U test revealed a consistent advantage for the experimental group regarding ER quality compared to the control group. This suggests that the EKB approach enabled students to discover and construct semantically robust ERs to a greater extent and with more remarkable thoroughness. The effect size results also revealed how EKB participants outperformed ESB participants with a substantial effect.

### Analysis of the correlation between ER and students' understanding

The pre-test was intended to identify the initial ability of the two groups before getting further intervention. Scores in the first experiment showed that both groups had the same average strength on the learning topic. The experimental group achieved a mean rank of 48.66 ( $SD = 10.94$ ), while the control group achieved a mean rank of 47.69 ( $SD = 16.64$ ). The pre-test scores from the second experiment unveiled a parallel proficiency level between both groups and consistency. The experimental group students attained a mean rank of 45.71 ( $SD = 12.60$ ), whereas the control group students attained a mean rank of 46.30 ( $SD = 15.23$ ).

As indicated by the Mann-Whitney U test results, there were no variances that were statistically significant in either the first or second experiment ( $Z = 0.000$ ;  $p = 1.0 > .05$ ;  $Z = -.043$ ;  $p = .966 > .05$ ). Pearson's  $r$  results indicated negligible effect sizes in both experiments, with  $r = 0.000$  and  $r = -0.006$ , respectively.

In order to evaluate the progress of the students, a post-test was administered subsequent to the interventions, which assessed their comprehension of instructional design. The statistical descriptions of the post-test results for the initial and subsequent experiments are provided in Table 5. The findings indicated that in both assessments, participants in the experimental group attained superior mean scores (87.50 and 90.71) compared to the control group (81.02 and 80.74).

**Table 5** Achievement statistics of the post-test scores for both groups

Experiment	Group	N	Min	Max	Median	Mean	SD
First experiment	Control group	27	63	100	87.50	81.02	10.612
	Experimental group	28	75	100	87.50	87.50	9.001
Second experiment	Control group	27	50	100	90	80.74	14.917
	Experimental group	28	80	100	90	90.71	7.164

The Mann-Whitney U test was employed to ascertain the level of differentiation in post-test scores between the two cohorts. Findings from the initial experiment indicated a significant disparity in students' comprehension between the groups ( $p = .030 < .05$ ). Pearson's  $r$  revealed a moderate effect size (0.31) in the analysis results. Similarly, the second experiment's results unveiled a noteworthy difference in post-test performances ( $p = .030 < .05$ ), with Pearson's  $r$  coefficient standing at 0.4, signifying a moderate effect magnitude.

Examining the correlation between ER size and quality scores with students' understanding aimed to establish the relationship between these variables. The conclusions drawn from the initial experiment regarding the correlation coefficients were examined, as illustrated in Table 6. The research identified a robust positive association between ER size and quality scores in both the control group ( $r_s = .828$  at  $p < .001$ ) and the experimental group ( $r_s = .947$  at  $p < .001$ ). Additionally, the control group did not observe any significant interrelationship between ER scores and students' achievements.

Different conditions in the experimental group showed reciprocal relations in all variables. There was a positive moderate association between ER size and post-test scores ( $r_s = .410$  at  $p < .05$ ) and ER quality ( $r_s = .400$  at  $p < .05$ ).

The results of the analysis of Spearman correlation coefficients in the second experiment are presented in Table 7. The consistent strong correlation between ER number and quality scores was evident. The Spearman rank correlation coefficient values were .961 for the control group and .971 for the experimental group, both at a significance level of  $p < .001$ . Within the control group, post-test scores demonstrated a moderate positive correlation with ER scores, with an ER size of .392 and ER quality of .388, both at a significance level of  $p < .05$ .

**Table 6** Coefficients of Spearman correlation for the initial investigation

Group		ER size	ER quality	Post-test
Control group	ER size		.828***	-.015
	ER quality	.828***		.222
Experimental group	ER size		.947***	.410*
	ER quality	.947***		.400*

Significant code: "\*" .05, "\*\*\*" .01, "\*\*\*\*" .001

**Table 7** Coefficients of Spearman correlation for the second investigation

Group		ER size	ER quality	Post-test
Control group	ER size		.961***	.392*
	ER quality	.961***		.388*
Experimental group	ER size		.971***	.480**
	ER quality	.971***		.477*

Significant code: "\*" .05, "\*\*\*" .01, "\*\*\*\*" .001

In the second experiment, the experimental group’s performance consistently exhibited a correlation between variables, mirroring the findings from the previous experiment. The Spearman rank correlation coefficient value between the post-test scores and ER size was .480, while ER quality was .477. The correlation related to the number of ERs was seen as significant at level  $p < .01$ . In contrast, the quality of ERs was at level  $p < .05$ .

The results of the correlation analysis between ER size and ER quality scores in both groups stated that there were strong positive correlations in all experiments. Furthermore, there is no constant correlation between ER scores and students’ comprehension in the control group. This achievement differed from the performance of students in the experimental group, indicating a positive correlation among accomplishments.

### Discussion

#### Research question 1

This research discovered that the EKB approach surpassed the ESB method regarding ER size and ER quality scores. The ER pattern on EKB demonstrates a close and uniform relationship between the initial original map and the new supplementary map. Students in the experimental group could identify more ERs than those in the control group. In ESB, it was also seen that students could link new knowledge with previous information, but they still needed to be directed to achieve good interconnection. Figure 6 illustrates the recognition of ER in a student from the experimental group. The concept on the original map is represented in orange; blue signifies the additional map, and the red-striped oval indicates ER identification.

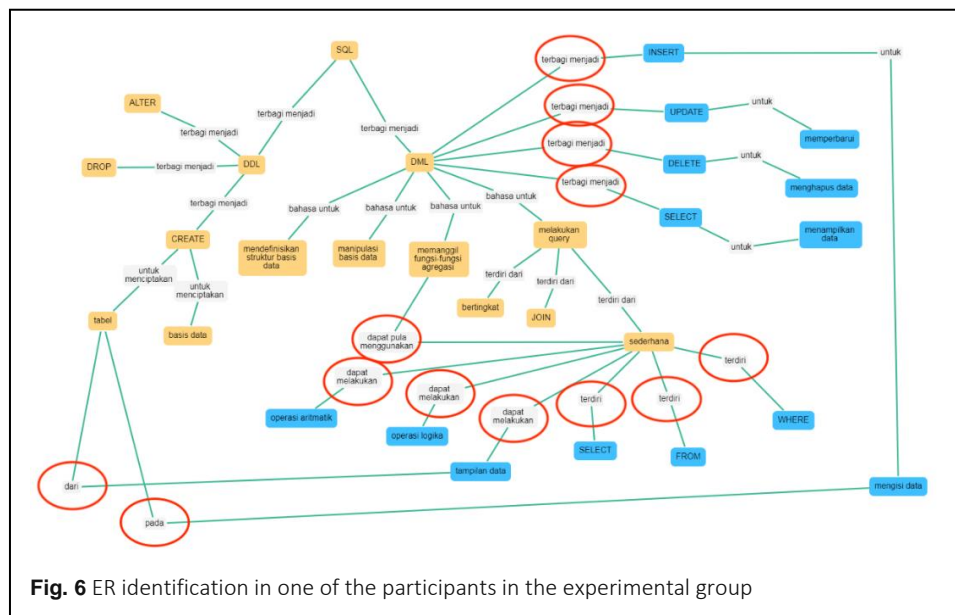


Fig. 6 ER identification in one of the participants in the experimental group

ER describes how learners could enhance their meaningful learning. Cañas and Novak (2008) argued that meaningful learning could be improved by connecting additional maps to existing ones. An essential attribute of meaningful learning involves generating a meticulously structured concept map (Cañas et al., 2015; Eshuis et al., 2022; Prasetya et al., 2022; Xu, 2022). Students' concept map on EKB not only associates one with another but also an excellent organization between one and the following materials.

The presence of kit components (provided a set of nodes and links) has an influential role in supporting extended concept mapping activities. The kit is derived from the instructor's map, which serves as the master map crafted by a teacher well-versed in the subject matter. It incentivizes pupils to develop novel conceptual maps, guaranteeing a methodically structured fundamental framework. Furthermore, students easily find critical concepts in new information and integrate them into the original map. Thus, students who use EKB have more opportunities to define ER, which describes the tight connection in the map expansion. The experimental results emphasized that the expansion of the original map was not merely through the idea of particular segments but is relatively evenly distributed in several sections. This condition proves that the EKB approach has more potential to increase meaningful learning through interrelatedness patterns.

## **Research question 2**

The extended map activity encourages students to integrate newly learned information with existing cognitive structures and achieve new knowledge. In knowledge construction, the learner does not merely recall the material but also transfers previous experience to solve new problems (Furtado et al., 2019; Mayer, 2002; Prasetya et al., 2022; Xu, 2022). This study proves that achieving ER scores on EKB positively impacts students' comprehension. The results of two experiments with different topics have demonstrated that students who use EKB consistently influence learning outcomes. Expansion yielded enhanced meaningful learning activities that are highly desirable for solving complicated problems.

Aligned with prior research (Pinandito et al., 2021; Prasetya et al., 2022), this study strongly asserts that students employing the EKB approach exhibit a heightened focus on connecting new knowledge to previously acquired information compared to those utilizing ESB. The initial experiment revealed consistently low performance in all variables for the control group, with marginal improvement in subsequent trials. Despite these enhancements, the control group still needed to reach the average achievements of the experimental group. In contrast, students in the experimental group employing EKB demonstrated sustained retention of prior and new knowledge, enabling them to tackle intricate problems effectively and achieve optimal, consistent outcomes.

## Limitations and future work

The present study acknowledges specific constraints that require careful consideration. Initially, the focus was on evaluating the efficacy of two prospective configurations for extension concept mapping using two sets of material sequences for accuracy. However, extending the scope by incorporating a more diverse array of material topics is crucial for a more holistic understanding. Additionally, the relatively modest size of the participant pool in this experiment underscores the need for future research initiatives to engage a larger and more diverse cohort. This approach will facilitate a more thorough examination of the expansive reach of extension concept mapping tools across a diverse array.

The primary objective of this research was to build upon previous studies that established the EKB approach's exceptional efficacy in enhancing students' grasp of assessment scores and conceptual map magnitudes, which outweighs that of the ESB. Further investigation in this domain may yield significant knowledge by exploring the associations between students' perceptions, map quality, map dimensions, and test scores. Moreover, delving into students' behavior during concept map creation is essential, and incorporating log data and other tools in future studies can offer a deeper understanding of students' activities in this context.

## Conclusion

In this experiment, we investigated two extended concept mapping tools (ESB and EKB) for novice users and analyzed the resulting concept map interrelatedness patterns measured using extension relationships (ER). This research provides a new contribution by revealing patterns of interrelatedness in extension concept mapping activities that connect previous and new knowledge in facilitating enhanced meaningful learning. The design of extended maps in both methodologies enables learners to revisit their existing knowledge, identify missing elements, incorporate new ideas and connections, and enhance the overall structure of their knowledge. However, EKB, which combines a closed-ended and reconstruction KB, facilitates enhanced meaningful learning compared to ESB. The results of two experiments on related topics reported an admirable and continuous EKB achievement.

These findings align with prior research findings, affirming the superiority of the EKB approach over ESB in post-test performance, as well as the quantity and quality of propositions. This study further elucidates that students employing the EKB method demonstrate a capacity for more intricately connected patterns compared to those utilizing ESB, as evidenced by the quantity and quality of ERs. Furthermore, achieving ER scores on EKB also positively affected students' comprehension. The patterns obtained answer the initial hypotheses and align with previous studies theories. Thus, this study highlights that the EKB approach facilitates learners' achievement of a high level of expertise and depth of knowledge.

### Abbreviations

ESB: Extended Scratch-Build; EKB: Extended Kit-Build; KB: Kit-Build; ER: Extension Relationship; SQL: Structured Query Language; ES: Effect Size.

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### Authors' contributions

This research is part of the university research grant project conducted by DDP. DDP analyzed the experiment results and prepared the initial manuscript. TW assisted in experiments and data collection. TH was the research partner who reviewed the experimental procedures and results. All authors read and approved the final manuscript.

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### Availability of data and materials

As a series of subsequent research papers are still in progress, it is temporarily impossible to share research data sets.

### Declarations

#### Competing interests

The authors declare that they have no competing interests.

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