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Effectiveness of goal free problems for students with learning experience

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Abstract: Goal Free is a problem presentation technique that does not include a specific question, in contrast to goal-given problems. Research on goal-free problems typically shows that this technique is more effective for novice students who have no prior experience with the topic. However, this study aims to explore the effectiveness of goal-free problems for students with prior learning experience, focusing on higher-order thinking skills (HOTS) and cognitive load. This quasi-experimental study used a factorial design of two problem presentation techniques that were compared: goal free vs goal given, in circle material. This study consisted of four phases, namely (1) Initial test; (2) Prior knowledge activation phase; (3) Learning phase (Acquisition phase), and (4) Final test (HOTS test). A total of 58 students (average age 19.6 years) were actively involved in this study. HOTS data were collected using a descriptive test (Cronbach's alpha = 0.669), while cognitive load was measured using a 9-point Likert scale. The results of the study concluded that students who studied circle material through goal free problems had better HOTS scores compared to students who studied goal given problems but this did not occur significantly. Likewise, the average cognitive load of students, it was found that students who studied using the goal free problems in the learning phase (acquisition phase) and the final test phase were lower when compared to the average cognitive load of students who studied through the goal given problems but this difference was not significant.

Keywords: Goal free problems, cognitive load, learning experience, higher-order thinking skills (HOTS), problem presentation techniques.

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Introduction

In Indonesia, problem solving is a familiar main activity in mathematics learning. The problems presented can be well-defined problems or ill-defined problems (Jonassen, 1997). Problems can be presented directly by the teacher or created by the students themselves. Problem solving can also be done independently or through group study.

Problem-solving learning is present because of a shift in perspective in understanding how students learn (Brunning, Scraw, & Norby, 2011). Learning is no longer seen as a one-way process, namely receiving information to be stored in students' memory. However, students learn by approaching each new problem or task with the knowledge they already have, assimilating new information, and building their own understanding (Kirschner, Sweller, & Clark, 2006). This means that the problem is not only solved by students but also brings new knowledge when the process of solving the existing problem.

Seeing the importance of the role of problems and problem-solving activities, it is important to have research on how to construct a good "problem" and relate it to how a person learns. One learning theory that pays attention to this is Cognitive Load Theory (CLT) (Sweller, Ayres, & Kalyuga, 2011).

CLT states that learning involves a memory system (cognitive system) to process the information being learned in building knowledge. The memory systems referred to in this case are sensory memory, working memory, and long-term memory (Paas, Renkl, & Sweller, 2003). Information will be received by sensory memory, which is then processed in working memory to think about its meaning and organize it with prior knowledge taken from long-term memory, and the results of this learning are then stored in long-term memory (Plass, Moreno, & Brünken, 2010). However, among the three memory systems, working memory has the most important role in the learning process; therefore, the capacity of working memory in processing information needs to be considered (Sweller, 2004).

In learning activities, according to Sweller et al. (2011), working memory is influenced by cognitive load, namely intrinsic cognitive load and extraneous cognitive load. Intrinsic cognitive load in learning is present because of the level of complexity of the teaching materials provided, while extraneous cognitive load in learning is determined by the presentation of the teaching materials. According to Kalyuga (2007), the learning process should minimize extraneous cognitive load. Proper presentation will provide a small cognitive load even though the material given has high complexity. Conversely, poorly presented material will provide excessive cognitive load even though the material given is easy material. One of the problem presentation techniques in learning that can minimize extraneous cognitive load so that it can improve problem-solving skills is goal-free problems (Ayres, 1993).

Goal-free problems are a problem presentation technique without specifying a specific end goal of the given problem. Goal-free problems are the opposite of goal-given problems, which are problem presentation techniques in general. Unlike goal-given problems that instruct to "determine a value of x," for example, goal-free problems use the instruction "determine as many values as possible" (Ayres, 1998). By not providing this end goal, students are believed to be able to use their limited working memory capacity to build knowledge to the maximum (Bobis, Sweller, & Cooper, 1994).

Some empirical evidence has shown that goal-free problems are significantly more effective than goal-given problems (Sugiman et al., 2019; Blegur, 2018). However, these studies are limited to beginner students (students who are just learning certain materials). There has been no research that explains the effectiveness of goal-free problems vs. goal-given problems for students who have had previous learning experience.

Other CLT-based learning strategy research shows that students' learning experiences can influence the effectiveness of the learning strategies used. For example, the worked example strategy is effective for beginner students because it minimizes extraneous cognitive load but presents a high cognitive load for students who already have learning experience (Retnowati, Ayres, & Sweller, 2010). Therefore, the worked example strategy is not recommended for students who already have learning experience (Kalyuga, 2001).

Departing from this phenomenon, this research was conducted. By juxtaposing goal-free problems vs. goal-given problems, this research suspects that goal-free problems are more significantly effective when compared to goal-given problems for students who already have learning experience. The variables measured in this study were high-level thinking skills (HOTS) and cognitive load. HOTS was chosen because it is a skill needed in problem-solving activities. Furthermore, this study was conducted on a group of students who already had classical learning experience related to the research material taken (Purnama & Retnowati, 2020).

Method

Research design

This research is a quasi-experimental research because the participants in the research were not placed in groups completely randomly. This study used a factorial design: Pre-test and Post-Test Control-Group with the aim of comparing how high-level mathematical thinking skills and students' cognitive load are as an effort to determine the effectiveness of learning between the experimental group that learned using goal free problems and the control group that learned using goal given problems. The pre-test was conducted to determine the initial abilities of the participants because the participants had previous learning experiences. The brief design of this study is described in Table 1.

Table 1. Research Design

Class/Group	*Pre-test*	Treatment	*Post-Test*
GF (Goal Free)	O	X_1	O
GG (Goal Given)	O	X_2	O

Information :

$X_1, X_2,$ = Learning according to experimental group
O = Subjected to Test

Time and Research Participants

This research was conducted for three days in May 2024. There were 59 students (average age 19.6 years) of the Mathematics Education study program, FKIP Undana Kupang NTT who were actively involved in this research. These students were students over the age of 15 years and had experience learning related to the material of the central angle and the circumference of a circle (research material) in a classical manner.

Research Materials and Procedures

The central angle and the circumference of a circle are the materials used in this study. This material is studied through four phases, namely pre-test (initial test); prior knowledge activation phase; learning phase (acquisition phase), and final test (HOTS test). The target competency achievement of each phase can be seen in Figure 1. The time allocation for the pre-test phase is 45 minutes. In this phase, retention questions related to the material of the central angle and the circumference of a circle are tested on students in both classes. The aim is to measure the initial understanding of the research subjects where the research subjects must come from the same starting point. This pre-test phase is held on the first day.

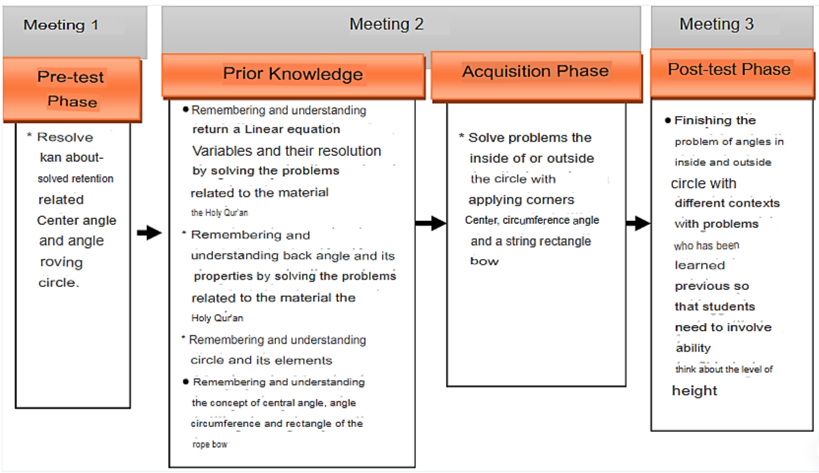


Figure 1. Competency achevement targets for each phase

For the second day, there are two phases carried out, namely the prior knowledge activation phase and the learning phase (acquisition phase). Students study in pairs (two people) in both phases, both in the experimental and control classes. Pairs are chosen so that students can discuss with each other in small groups. For the prior knowledge activation phase, there are four basic materials. Details of the materials can be seen in Table 2. The time allocation for the prior knowledge activation phase is 45 minutes. The next phase is the learning phase (acquisition phase). In this phase, students learn through goal-given and goal-free problem presentation techniques. In this phase, students are expected to learn in depth about how to apply all the theorems and materials that have been studied. A total of eight mathematical problems are presented in the form of a booklet with instructions on the front. The instructions for the goal-free environment are "determine the size of the angle in the circle that is not yet known as much as possible", while for the goal-given environment are "determine the size of angle x". Figures 2 and 3 are examples of problems presented in goal-free and goal-given. In this phase, students' cognitive load is also measured. The instrument used is a 9-point Likert scale with a range of 1 = "very-very easy" to 9 = "very-very difficult". This Likert scale is listed at the end of each question that students work on. The time allocation for working on the problems in this phase is 60 minutes.

Table 2. Research Materials

No.	Description
A.	**Angle theorem**
1.	Supplemental angles add up180^0
2.	The number of angles that make up one complete rotation is360^0
3.	The measures of opposite angles are equal.
4.	The sum of the angles in a triangle is180^0
5.	The leg angles of an isosceles triangle are the same. An isosceles triangle is a triangle that has 2 sides of the same length.
6.	The angles of an equilateral triangle are the same, namely . An equilateral triangle is a triangle whose three sides are the same length.60^0
7.	The sum of the angles in a quadrilateral is360^0
B.	**Solving Linear Equations in One Variable**
C.	**Definition and elements of a circle**
D.	**Theorems of central angle and circumference of a circle**
1.	If a central angle and an angle at the circumference of a circle face the same arc then the angle of the circumference of the circle = . In other words, the size of the angle at the center of the circle$\frac{1}{2} \times$ sudut pusat lingkaran $= 2 \times$ sudut keliling lingkaran
2.	Perimeter angles facing the same arc have the same angle measure.
3.	The angle at the circumference facing the diameter of the circle is right angled.(90^0)
4.	In a chord quadrilateral the sum of the opposite angles is equal to180^0

Determine as many unknown angles as possible!

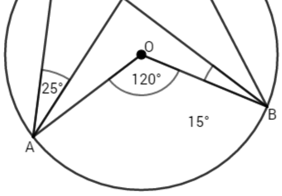


Figure 2. Goal Free Problem

Determine the size of angle EAO!

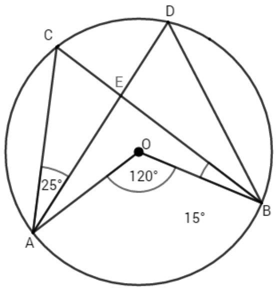
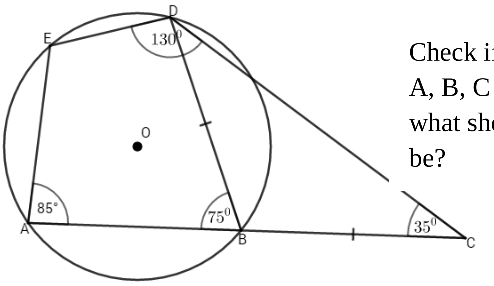


Figure 3. Goal Given Problem

For the last phase, the post-test phase was conducted on the third day. This final test aims to measure students' higher order thinking skills. There are 5 essay questions (Cronbrach's alpha = 0.67) that are tested individually, with a time allocation of 60 minutes. These questions have higher characteristics and levels of difficulty when compared to the questions studied in the learning phase.These questions have been validated by 2 experts. Figure 4 is an example of a high-level thinking ability test item used in the study. As for c*cognitive load*also measured in this phase.



Check if the measures of angles A, B, C and D are correct? If not, what should the angle measures be?

Figure 4. HOTS test questions

Results and Discussion

Results

The pre-test results showed that participants started from the same starting point (initial ability) where the average initial ability of the experimental class was44.05 ($SE = 4.01$)while the control class. Table 3 shows the results of the research data analysis.44.60 ($SE = 4.09$).

Table 3. Significance value, average and standard deviation of the results of each variable

Variables	*p*	*r*	*Goal Free*(N= 31)		*Goal Given*(N=27)		Conclusion
			$\bar{X}$	SE	$\bar{X}$	SE	
Initial Test	-	-	44.05	4.01	44.60	4.09	Students start from the same starting point
High-level thinking skills (HOTS)	0.658	0.275.	60.51	4.53	46.73	4.53	*Goal free> goal given*but not significant.
Cognitive Load							
Learning Phase	0.497	0.413	4.28	0.24	5.59	0.31	*Goal free< goal given*but not

Variables	p	r	***Goal Free*(N= 31)**		***Goal Given*(N=27)**		**Conclusion**
			$\overline{X}$	**SE**	$\overline{X}$	**SE**	
							significant.
HOTS Test Phase	0.664	0.464	4.63	0.32	6.54	0.37	*Goal free*< *goal given*but not significant.

Data Analysis High Level Thinking Skills

The results of the analysis of high-level thinking ability test data for students show thattThere is no significant difference between the average (mean) high-level thinking ability of students who learn through the goal-free problems presentation technique and the average (mean) high-level thinking ability of students who learn through the goal-given problems presentation technique. This statement is supported by the significance value, with $p = 0.658 > 0.05 t(56) = 2.14$which provides value$r = 0.275$. The average value of students who learn through presentation techniquesgoal free problems is (, while the average value of students who learn through the goal given problems presentation technique is$60.51 SE = 4.53$) $46.73(SE = 4.53)$. Mark$r = 0.275$describes a moderate effect size. In other words, learning through the goal free problems presentation technique is more effective when compared to goal given problems in circle learning in terms of students' high-level thinking skills. However, it is not significantly more effective.

Cognitive load Data Analysis

1. **Cognitive Load Data Analysis During the Learning Phase**

The results of testing on cognitive load data during the learning phase show that the significance value with $p = 0.497 > 0.05 t(56) = -3.39$ so that$r = 0.413$. This means thattThere is no significant difference between the average (mean) cognitive load of students who learn through the goal free problems presentation technique in the learning phase (Acquisition phase) with the average (mean) cognitive load of students who learn through the goal given problems presentation technique. The average cognitive load of students during the learning phase through the goal free problems presentation technique is4.28 (). Average cognitive load$SE = 0.24$students who learn through the goal given problems presentation technique learning phase (Acquisition phase)is (). The value gives the meaning of the moderate effect size.5.59 $SE = 0.31 r = 0.413$. In other wordsThe goal free problem presentation technique is better when compared to goal given because it presents a smaller cognitive load during the learning phase. However, it is not significantly more effective.

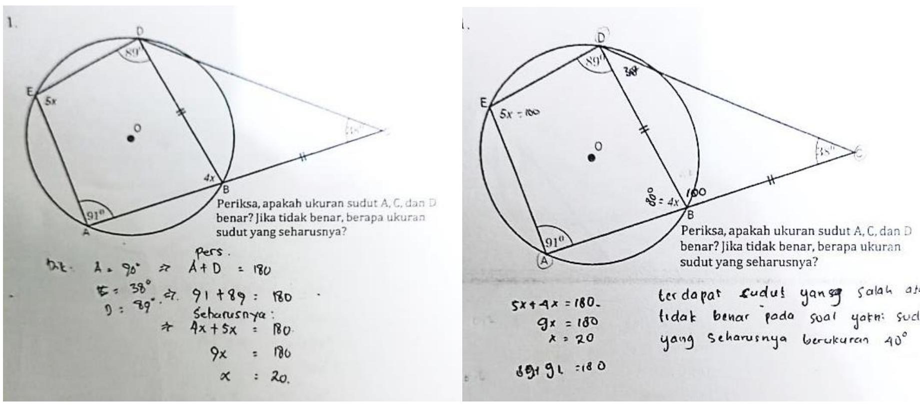
2. **Cognitive Load Data Analysis During the Final Test Phase**

Testing on cognitive load data during the final test phase aims to measure students' cognitive load when completing high-level thinking ability test questions. The results obtained are not much different from the results of testing on cognitive load data during the learning phase. Based on the results of the significance value test$p = 0.664 > 0.05$. It means tThere is no significant difference between the average (mean) cognitive load of students who learn through the goal free problems presentation technique during the final test phase when compared to the average (mean) cognitive load of students who learn through the goal given problems presentation technique during the final test phase. Furthermore, the value$t(56) = -3.92$so that it provides a value that describes the size of the moderate effect. The average cognitive load$r = 0.464$students who learn through the goal free problems presentation technique in the final test phaseis while the average cognitive load 4.63 ($SE = 0.32$)students who learn through the goal given problems presentation techniqueonfinal test phaseis. So it can be concluded that the goal free problem presentation technique is better when compared to goal given because it presents a smaller cognitive load during the high-level thinking ability test phase but is not significantly more effective.6.54 $(SE = 0.37)$

Discussion

The results of the data analysis show that students who study goal-free problems have better high-level thinking ability scores compared to students who study goal-given problems. These findings confirm the results of previous research, where students who study goal-free problems have higher final test scores compared to students who study goal-given problems. This is because the presentation technique of goal-given problems leads students to use the means-ends analysis strategy, namely solving problems from what is asked. By using the principle of working backwards, the means-ends strategy guides students to determine sub-sub goals, namely which parts must be sought first before obtaining the goal (the specific goal being asked). In determining these sub-sub goals, many students make mistakes. This incident, referred to as the stage effect, results in working memory, which has limited capacity, processing information inefficiently. The impact is that there is no acquisition of certain procedural schemes. The problem is solved, but the process of building knowledge occurs ineffectively. So, it is not surprising that when faced with new problems (problems that require high-level thinking skills), students have difficulty recalling the knowledge they have learned (Ayres, 1993, 1998; Blegur, 2018; Bobis et al., 1994; Maulida et al., 2022; Purnama & Retnowati, 2020; Sugiman et al., 2019).

In contrast to the goal-free problems presentation technique, non-specific questions are deliberately created to prevent students from using the means-ends analysis strategy. The non-specific questions that exist will only make students understand the information available and how to determine the solution (determining as many answers as possible). As a result, students will learn to work forward from what is known and learn how to solve problems only with the information available. This process will enable students to build knowledge related to the material being studied well. Good knowledge development will be seen when students are faced with new problems. Students can apply the knowledge they have learned in solving problems. This is the reason why students who learn through the goal-free problems presentation technique have better high-level thinking ability scores compared to students who learn through the goal-given problems presentation technique (Sweller et al., 2011; Ayres, 1993; Kalyuga, Cognitive Load Factors in the Instructional Design for Advanced Learners; Sweller, Ayres, & Kalyuga, Cognitive Load Theory; Blegur, Oktaviani, & Retnowati, 2017).



(a) (b)

Figure 5. Example of Student High-Level Thinking Ability Test Answers on Question 1

Figure (a) shows that students who learn through goal given problems are unable to find an efficient strategy to answer the existing problems. Students only managed to determine the value xxx and did not continue their work. In contrast, Figure (b) shows that students can independently find efficient strategies to solve problems. Figure (b) shows students solving problems using the principle of working forward. After determining the value of x correctly, students then enter it into the equation, followed by checking each angle using the correct theorems. In the end, students are able to provide the correct conclusion to the requested problem. This is the impact of learning using the goal-free problems presentation technique.

On the other hand, this study also found that goal-free problems can indeed improve students' high-level thinking ability scores better when compared to goal given problems, but it does not occur significantly. This result is slightly different from the research results mentioned above. The classical learning experience related to research material at the previous level is thought to be the cause of this. The existing learning experience makes students have prior knowledge. Like the worked example effect, which will provide a redundant effect for students with prior knowledge, it is suspected that the same thing also happened to the goal-free presentation technique. However, this assumption still needs further empirical proof.

Presence of cognitive load in working memory will be inversely proportional to the high-level thinking ability score obtained. A good high-level thinking ability score indicates that the cognitive load present is low, and vice versa. This opinion is supported by the results of a study which found that the goal-free problem presentation technique is better when compared to goal-given because it presents a smaller cognitive load, both in the learning phase (acquisition phase) and during the test phase. For the learning phase, these results are in line with the findings of Kalyuga et al. (2003) and Kalyuga (2007), but a little different from Sweller et al. (2011). For the test phase, these results are in line with the research results of Blegur (2018), Maulida et al. (2022), Purnama & Retnowati (2020), and Sugiman et al. (2019).

As previously explained, the presentation technique of goal-given problems uses means-end strategies that cause stage effects. Stage effects cause students to process information excessively. As a result, it presents a cognitive load that is high in working memory during study. High cognitive load on working memory will prevent students from storing knowledge well in long-term memory. Insufficient availability of knowledge makes it difficult for students to solve a new problem, which of course will present a high intrinsic cognitive load. So, it is not surprising that students who learn through the goal-given problems presentation technique experience high cognitive load when completing the final test questions.

Different from students who learn through goal-free problems presentation techniques. Working without knowing the specific goal reduces students' cognitive load when solving problems. As a result, it provides more capacity in students' working memory for the process of knowledge acquisition and automation. In addition, the principle of working forward can reduce the interactivity between elements of information being processed by working memory. Reducing element interaction can result in a reduction in extraneous cognitive load and improve learning outcomes. That is why students experience low cognitive load during the learning phase.

Furthermore, a good knowledge building process makes the availability of initial knowledge sufficient in long-term memory. As a result, when students are faced with a new problem, working memory can recall existing knowledge so that they can process intrinsic cognitive load well. So, it is not surprising that students who learn through the goal-free problems presentation technique do not experience high cognitive load when completing the final test questions.

Conclusion

The results of this study indicate that goal free problems in the context of mathematics learning for students who have had learning experience provide better learning outcomes when compared to goal given problems but do not occur significantly. Likewise, from the cognitive load factor, the results show that goal free problems in the context of mathematics learning for students who have had learning experience present a lower cognitive load when compared to goal given problems but do not occur significantly. The factor causing insignificance is thought to be due to the learning experience they have, but this still needs further research. More in-depth research related to the selection of the first step of student work and so on is also still needed as an illustration of how efficient the goal free presentation technique is. In the end, despite the insignificance that occurs, this study concludes that goal free problems are effective for students who have had learning experience because they can improve high-level thinking skills and reduce cognitive load.

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