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Local Instructional Theory of Definite Integral Learning to Improve Prospective Mathematics Teachers' Mathematical Problem-Solving Skills and Self-Regulated Learning

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Abstract

Mathematical problem-solving skills and self-regulated learning (SRL) are essential components of effective mathematics education in the 21st century. But recent studies indicate that prospective mathematics teachers' mathematical problem-solving skills and self-regulated learning in calculus, particularly in the topic of definite integrals, still remain at a low level. To solve this problem, this study tried to design a Local Instructional Theory (LIT) based on Realistic Mathematics Education (RME) on Definite Integrals learning. The LIT consist of Hypothetical Learning Trajectory (HLT), Lecturers' book and prospective mathematics teachers' book. This study is design research using Plomp model on the third phase (field test) using quasi-experimental approach (non-equivalent post-test only groups design). The participants of this study are 32 prospective mathematics teachers that divided into experimental and control group. The post-test consists of mathematical problem-solving skills test and self-regulated learning questionnaire. Based on the post-test, the data was analyzed using the compare means test with prerequisite test done first, namely normality and homogeneity test. The result shows that the LIT based on RME is effective to improve students' mathematical problem-solving skills and all of the aspect of mathematical problem-solving skills. For the self-regulated learning, there is no significant effect of using LIT based on RME, only in goal setting and task strategies aspect.

Keywords: Local Instructional Theory, Mathematical Problem-Solving Skills, Prospective Mathematics Teachers, Realistic Mathematics Education, Self-Regulated Learning.

Introduction

Mathematical problem-solving skills and self-regulated learning (SRL) are essential components of effective mathematics education in the 21st century. Students who possess strong mathematical problem-solving skills are better equipped to analyze, model, and reason through complex situations, enabling deeper conceptual understanding and long-term retention (1, 2). Research shows that mathematical problem-solving fosters creativity, critical thinking, and perseverance in learning (3, 4), while SRL empowers learners to plan, monitor, and evaluate their strategies to reach learning goals effectively (5, 6). Studies indicate a strong correlation between SRL and mathematical problem-solving performance, suggesting that self-regulated learners demonstrate higher persistence and adaptability when confronted with challenging tasks (7). As a prospective mathematics teachers, this aspect is essential because how can they facilitate students' mathematical problem-solving skills and self-regulated learning if they are the problem. This is because mathematics teacher's proficiency (including their knowledge of mathematical problem-solving skills) is related to student outcomes (8). Furthermore, on their bachelor degree, the mathematics they learn are also deeper and abstract, for example the concept of definite integral.

Recent studies indicate that prospective mathematics teachers' mathematical problem-solving skills and self-regulated learning (SRL) in calculus, particularly in the topic of definite integrals, remain at a low level. Many students find it difficult to connect the concepts of sigma notation, area, and the definition of definite integrals, which hinders their ability to solve contextual problems effectively.

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Research reported that prospective mathematics teachers often struggle to recall prior knowledge and select appropriate strategies when solving integral problems, revealing weaknesses in metacognitive and procedural understanding (9). Prospective mathematics teachers also show weak performance on the transition of representation skills which makes them weaker on solving problems in definite integral topics (10). Furthermore, when students can compute integrals, they often fail to interpret the meaning of negative values or contextualize results within real-world applications, reflecting a lack of conceptual depth (11). These issues are compounded by weak self-regulated learning skills; students frequently demonstrate low initiative, poor monitoring of understanding, and limited reflection on errors (12). As a result, students tend to depend on others instead of employing suitable strategic approaches to overcome challenges independently.

One promising solution to overcome students' low mathematical problem-solving skills and self-regulated learning (SRL) is the development of a Local Instructional Theory (LIT) grounded in the Realistic Mathematics Education (RME) approach. Local Instructional Theory (LIT) is a theoretically grounded and empirically informed framework that describes how learning in a specific domain can be fostered through a designed sequence of instructional activities, including the learning goals, instructional tasks, tools, representations, and anticipated student thinking (13). When combined with RME, learning becomes more meaningful because mathematical concepts are developed from real-life contexts and students' informal strategies, gradually formalized through guided reinvention (14). Through contextual problems and progressive mathematization, students are encouraged to take ownership of their learning, reflect on strategies, and regulate their cognitive processes (15, 16).

Recent studies confirm that LIT based on RME significantly improve students' mathematical reasoning skills and problem-solving skills. In derivative topics, developing LIT based on RME with flying fox ride context are effective in improving students' mathematical problem-solving skills for 11th grade students (17). In theory of multiplication topics, developing LIT based on RME with are effective in improving students' mathematical problem-solving skills for 3rd grade students (18). In theory of division topics, developing LIT based on RME with trading and teachers, congklak games, skill-making activities, borrowing books and stationery, saving activities, drawing and buying and selling activities are effective in improving students' mathematical problem-solving skills for 3rd grade students (19). In trigonometric ratios topics, developing LIT based on RME with actual activity using tables and ropes are effective in improving students' conceptual understanding for 10th grade students (20). In systems of linear equations in two variables topics, developing LIT based on RME with Jakabaring Tourism in Palembang context are effective in improving students' conceptual understanding for 8th grade students (21).

Based on the previous researches, it can be seen that there is still no research that solving the combination of low problem-solving proficiency and insufficient SRL. This study trying to solve these problems combination through developing an LIT based on RME framework. Furthermore, in case of limitations of these studies, the nature of LIT design research is the detail and small scale of field test, which means the need of designing in others topics is always appears. In the current study, the topic is definite integrals where specifically prospective mathematics teachers have problems with. Therefore, this study aims to develop local instructional theory of definite integral learning that able to improve prospective mathematics teachers' mathematical problem-solving skills and self-regulated learning. The research questions for this study are "Is local instructional theory of definite integral learning significant to improve prospective mathematics teachers' mathematical problem-solving skills and self-regulated learning?"

Methodology

Based on the introduction, this study tried to design a Local Instructional Theory based on Realistic Mathematics Education on Definite Integrals learning that can improve students' mathematical problem-solving skills and self-regulated learning. This study is design research using Plomp model with three phases, preliminary research, prototyping phase, and assessment phase. The design of LIT based on RME already through preliminary research and prototyping phase (formative evaluation), such as self-evaluation, expert review, focus group discussion, one-to-one and small group evaluation. The result shows that the LIT can be used in the learning process because it is already valid and practical. The validity and practicality of the LIT can be seen in Table 1.

This paper will discuss the third phase of the design research which is assessment phase (field test). To assess, the approach used in this study become quasi-experimental using non-equivalent posttest only groups design. The design of this research can be seen in Table 2.

Table 1: Validity and Practicality of the LIT

Component	Validity (%)	Practicality (%)
HLT	74.41 (Valid)	85 (Very practice)
Lecturer's Book	85 (Valid)	86.46 (Very practice)
Students' Book	73.89 (Valid)	85.44 (Very practice)

Table 2: Quasi-Experimental Using Non-Equivalent Posttest Only Groups Design

Class	Treatment	Test
Experiment	LIT based on RME	Posttest
Control	-	Posttest

The participants of this study are 32 prospective mathematics teachers in Universitas Adzkia, Padang, Indonesia that took Calculus 1 course. These 32 prospective mathematics teachers are divided into two groups, so that the initial level of them are equal. To do the sampling, compare means test are initiated (ANOVA) based on the assignment mark in Calculus 1 course. The ANOVA test showed 0.172 significance value which shows that there are no differences between the two classes.

The Local Instructional Theory (LIT) of definite integral learning used in this study was loaded to lecturers' book and prospective mathematics teachers' book. The lecturers' book is equipped with Hypothetical Learning Trajectory (HLT). Nevertheless, each book has similar activity that will help students understand the concept of definite integral using realistic mathematics education approach. There are several objectives that will be achieved after learning using this LIT, namely: students can...

a. Understand the notation and sum of sigma,
b. Solve preliminary area problems,
c. Understand definite integrals,
d. Understand the first fundamental theorem of calculus,
e. Understand the second fundamental theorem of calculus and the average theorem for integrals,
f. Complete definite integral calculations.

According to the learning objectives, the LIT are divided into 6 meetings, with each objectives every meeting. Learning activities in LIT for each meeting are in accordance with the RME principle, namely that the problems presented are contextual, use mathematization models, use production and construction, use interactivity, and are interconnected. These activities are designed to be considered capable of improving mathematical problem-solving skills and student's self-regulated learning in prototyping phase, namely validity by experts and practicality by lecturers and students. The detail of the topics each meeting and the problems given can be seen in Table 3.

Table 3: Meeting Details

Meeting	Topics	Detail	Problems given
1	the notation and sum of sigma,	Learning the concept of definite integrals begins with an understanding of the sum notation (sigma, $\sum$) as a short form of repeated addition. This approach aims to make it easier for students to understand definite integrals as the limit of Riemann sums.	1. Students were given a scenario about the number of handshakes in a meeting with 20 participants. They were asked to count the number of handshakes explicitly before constructing a pattern in sigma notation. $\sum_{k=1}^{n-1} k = \frac{n(n-1)}{2}$ 2. Students calculate the total prize in 12 days using explicit addition or using sigma notation and sum, namely $\sum_{k=1}^{12} \frac{k(k+1)}{2}$

Meeting	Topics	Detail	Problems given
			3. Students calculate the total number of cubes in a pyramid-shaped stack. Sigma notation is used to calculate the total number of cubes.
2	preliminary area problems	The concept of area under a curve is introduced as a first step in understanding definite integrals. Students are encouraged to understand how the area of a region can be calculated using the Riemann sum approach.	1. Students calculate the distance traveled by the bird using speed as a function of time. They construct the sum using a trapezoidal approximation before using sigma notation:$\sum_{i=1}^{n} f(x_i)\Delta x$ 2. Students measured plant growth by calculating the area under the growth rate curve. They used estimation methods to find the amount and total growth over several days.
3	definite integrals	At this stage, students are introduced to the concept of the definite integral as the limit of a Riemann sum. This understanding is gained after students understand the relationship between the sigma sum and the area under the curve.	1. Students calculate the cost of groceries based on the price per kilogram. They write the total cost in integral form$\int_a^b f(x)dx$. 2. Students calculate the volume of water flowing in an irrigation system using the flow rate function. They apply the concept of definite integrals to calculate the total volume. 3. Students are asked to calculate integrals according to given upper and lower limits using a designed numerical method. Through this activity, students begin to understand how integrals are used in real-world calculations.
4	the first fundamental theorem of calculus	The first fundamental theorem of calculus states that if $F(x)$ is an antiderivative of $f(x)$, then the definite integral of $f(x)$ can be computed as $\int_a^b f(x)\,dx = F(b) - F(a)$	1. Students are given a function for the growth rate of a plant. They calculate the total amount of water absorbed by the plant using the antiderivative. 2. Students analyze the relationship between the amount of ingredients used and the total cooking time. They find derivatives and antiderivatives in the context of cooking time.
5	the second fundamental theorem of calculus and the average theorem for integrals	This theorem states that the definite integral of a function can be used to find the original function.	1. Students calculate the amount of paint needed for a painting process. They use definite integrals to calculate total paint consumption. 2. Students calculated the total energy used by the stage lights for one hour. Using definite integrals, they found the total energy consumed. 3. Students are asked to calculate the average speed of a machine over a given time interval. Students calculate using the average integral.
6	definite integral calculations	At this stage, students are invited to understand how to calculate integrals using a numerical approach.	1. Students use the Riemann sum to calculate distance traveled from speed. They use the left, right, and center Riemann methods to find the best estimate. 2. Students calculated the total amount of water used over 2 hours based on the flow rate. They applied the trapezoidal and Simpson's methods to calculate definite integrals. 3. Students are asked to calculate the time and speed at which the ball will hit the ground. Students will calculate using integral equations, knowing gravity.

The post-test was conducted using mathematical problem-solving skills test and self-regulated learning questionnaire. The mathematical problem-solving skills test contains of 7 questions where every question used to assess all four indicators of problem-solving skills with score scale 0-4. The indicators are understanding the problem, devising a plan, carrying out the plan, and looking back. The validity of the test is based on the expert reviews from 3 experts in mathematics education, after the test is valid, reliability test conducted. The reliability test of the mathematical problem-solving skills test shows sig. 0.664 which means the test are reliable. The self-regulated learning questionnaire contains of 30 items, with 6 items each indicators of self-regulated learning with score scale 1-5. The indicators are goal setting, task strategies, time management, help seeking, and self-evaluation. The validity of the questionnaire is based on the expert reviews from 3 experts in mathematics education, after the questionnaire is valid, reliability test conducted. The reliability test of the self-regulated learning questionnaire shows sig. 0.8444 which means the questionnaire are reliable.

Based on the post-test, the data will be analyzed using compare means test. To determine what kind of test will be used prerequisite test done first, normality and homogeneity test. If the data was normal, the homogeneity test will be done, if the data is homogenous then the compare means test will be t test otherwise t' test. If the data is not normal, then the compare means test will be U Mann-Whitney test.

Results and Discussion

The Effect on Prospective Mathematics Teachers' Mathematical Problem Solving

Based on the mathematical problem-solving posttest, there is a significant gap of the result. Based on the test, only one student in experiment class that got 66.96% and the others got >75%. For the control class, only 6 students that got >75. The result of the test can be seen in Table 4.

Table 4: The Result of the Mathematical Problem-Solving Posttest

Class	Means	Median	Variance	Std. deviation	Min.	Max	Range	IQR	Skw.	Kurt.
Experiment	86.83	87.5	59.7	7.73	66.96	95.54	28.58	10.26	-1.17	1.66
Control	66.46	68.75	367.03	19.16	36.61	91.07	54.46	37.05	-0.31	-1.37

Based on the table 4, the experimental class achieved a higher mean score (86.83) and median (87.5) than the control class (mean = 66.46, median = 68.75), indicating better overall performance after the treatment. The variance (59.7) and standard deviation (7.73) of the experimental class were lower than those of the control class (variance = 367.03, standard deviation = 19.16), showing that the experimental group's scores were more consistent and less spread out. The minimum and maximum scores for the experimental class were 66.96 and 95.54, respectively, with a range of 28.58, while the control class ranged from 36.61 to 91.07 (range = 54.46). The interquartile range (IQR) was 10.26 for the experimental group and 37.05 for the control group, confirming that the middle 50% of scores in the experimental class were more tightly clustered. In terms of distribution shape, the skewness (−1.17) of the experimental group indicates a slightly left-skewed distribution, while the control group (−0.31) is closer to symmetrical. The kurtosis values (1.66 for experimental and −1.37 for control) suggest that the experimental class's score distribution was more peaked, whereas the control class's distribution was flatter. Overall, the results show that the experimental class not only achieved higher performance but also demonstrated more consistent and concentrated scores than the control class. Furthermore, based on the indicators, the result of the mathematical problem-solving posttest can be seen in Table 5.

Table 5: The Result of the Mathematical Problem-Solving Posttest Based on Indicators

Class	Means	Median	Variance	Std. deviation	Min.	Max	Range	IQR	Skw.	Kurt.
				Understanding the problem						
Experiment	95.98	96.33	20.19	4.49	85.71	100	14.29	6.25	-1.11	0.4
Control	77.07	78.57	153.92	12.41	57.14	96.43	39.29	23.21	-0.22	-1.31
				Devising a plan						
Experiment	82.81	82.14	87.12	9.33	64.29	96.43	32.14	17.86	-0.23	-0.78
Control	69.87	73.22	307.79	17.54	32.14	92.86	60.72	24.11	-0.67	-0.23
				Carrying out the plan						
Experiment	83.93	85.71	112.27	10.6	53.57	96.43	42.86	12.51	-1.68	3.62
Control	64.73	67.86	438.57	20.94	25	89.29	64.29	34.82	-0.5	-1
				Looking back						
Experiment	84.6	87.5	150.9	12.28	50	96.43	46.43	12.51	-1.79	3.25
Control	53.57	57.15	1137.74	33.73	0	92.86	92.86	66.97	-0.18	-1.65

In understanding the problem, the experimental class obtained a higher mean score (95.98) and median (96.33) than the control class (mean = 77.07; median = 78.57), indicating better comprehension of problem statements. The experimental group showed lower variance (20.19) and standard deviation (4.49) compared to the control group (variance = 153.92; SD = 12.41), suggesting more consistent understanding among students. The skewness (−1.11) and kurtosis (0.4) values indicate a slightly left-skewed and moderately peaked distribution in the experimental class, while the control class data were nearly symmetrical and flatter.

For devising a plan, the experimental class achieved a higher mean (82.81) and median (82.14) than the control class (mean = 69.87; median = 73.22). The smaller variance (87.12) and standard deviation (9.33) in the experimental class compared to the control class (variance = 307.79; SD = 17.54) show greater consistency in planning ability. The range and IQR values also support this, indicating more concentrated scores in the experimental group.

When carrying out the plan devised, the experimental class recorded a mean of 83.93 and median of 85.71, substantially higher than the control class (mean = 64.73; median = 67.86). The smaller variance (112.27) and SD (10.6) in the experimental group, compared to the control group (variance = 438.57; SD = 20.94), indicate more stable performance. The skewness and kurtosis (−1.68 and 3.62) reveal that the distribution is left-skewed and sharply peaked, suggesting that most students achieved high scores.

In the looking back indicator, the experimental class again outperformed the control class, with a mean of 84.6 versus 53.57. The control class exhibited a very high variance (1137.74) and SD (33.73), showing large variability among students. The experimental group's lower variance (150.9) and SD (12.28) indicate more consistent reflective checking behavior. The skewness and kurtosis values (−1.79 and 3.25) suggest that the experimental class distribution was left-skewed and sharply peaked, whereas the control class was flatter and widely spread.

Across all four indicators, the experimental class consistently achieved higher mean scores and lower variability compared to the control class. This implies that the applied instructional treatment effectively enhanced students' mathematical problem solving in every stage—understanding problems, planning, executing, and reflecting on solutions. The distributions in the experimental group tend to be left-skewed and peaked, indicating that most students reached high performance levels with consistent results.

The result of the normality, homogeneity, means comparison test can be seen in Table 6.

Table 6: The Result of Normality, Homogeneity and Effectivity Test of LIT to Students' Mathematical Problem Solving

Aspect	Test	Class	Significance	Conclusion
Mathematical problem solving	Normality	Experiment	0.094	Normal
		Control	0.095	Normal
	Homogeneity		0.000	Not homogen
	Effectivity (t' test)		0.001	There is difference
Understanding the problem	Normality	Experiment	0.004	Not normal
		Control	0.266	Normal
	Homogeneity		0.000	Not homogen
	Effectivity (Mann-Whitney U test)		0.000	There is difference
Devising a plan	Normality	Experiment	0.278	Normal
		Control	0.318	Normal
	Homogeneity		0.012	Not homogen
	Effectivity (t' test)		0.016	There is difference
Carrying out the plan	Normality	Experiment	0.016	Not normal
		Control	0.089	Normal
	Homogeneity		0.002	Not homogen
	Effectivity (Mann-Whitney U test)		0.004	There is difference
Looking back	Normality	Experiment	0.002	Not normal
		Control	0.034	Not normal
	Homogeneity		0.000	Not homogen
	Effectivity (Mann-Whitney U test)		0.007	There is difference

The results in Table 6 indicate that the implementation of Local Instructional Theory (LIT) based on the Realistic Mathematics Education (RME) approach significantly improved students' mathematical problem-solving skills across all indicators. Statistical analysis showed p-values below 0.05 for all problem-solving aspects—understanding the problem (0.000), devising a plan (0.016), carrying out the plan (0.004), and looking back (0.007)—suggesting meaningful differences between the experimental and control groups. This finding implies that the contextual and student-centered nature of RME helps students build stronger connections between real-life experiences and mathematical concepts. Similarly to previous study found that integrating contextual tasks in calculus improved students' understanding of complex topics such as differentiation and integration, supporting the argument that LIT–RME promotes progressive mathematization and higher-order reasoning (9).

These results align with a growing body of research that demonstrates the effectiveness of LIT and RME in enhancing students' mathematical reasoning, representation, and problem-solving capabilities. Modern problem-solving pedagogy, when grounded in context and conceptual exploration, leads to better procedural fluency and strategic reasoning (1). Previous study also found similar gains in students' mathematical problem-solving skills when problem-based models were implemented, underscoring the importance of active learning and student autonomy (22). Collectively, these findings confirm that the LIT–RME approach is consistent with current theoretical perspectives that view mathematical understanding as a process of guided reinvention through meaningful engagement and reflection.

However, while the positive effects observed in this study correspond with much of the literature, recent meta-analyses suggest that the success of RME and similar interventions is highly dependent on implementation quality, teacher support, and contextual adaptation. RME requires careful alignment between learning trajectories and classroom practices to maintain coherence between informal and formal reasoning stages (15). Therefore, although this study provides strong evidence of the effectiveness of LIT–RME for enhancing mathematical problem-solving skills, future research should include measures of implementation fidelity, effect size estimation, and long-term retention to ensure that the observed improvements are sustainable and generalizable across learning contexts.

Table 7: The Result of Self-Regulated Learning Questionnaire

Class	Means	Median	Variance	Std. deviation	Min.	Max	Range	IQR	Skw.	Kurt.
Experiment	118.5	118.5	56.4	7.51	106	130	24	13.75	0.078	-1.15
Control	96.75	95.5	138.47	11.77	74	115	41	16.5	-0.16	-0.36

The Effect on Prospective Mathematics Teachers' Self-Regulated Learning

The result of self-regulated learning questionnaire can be seen in Table 7.

Table 7 shows the results of the self-regulated learning questionnaire administered to the experimental and control classes. The experimental class, which received the treatment, achieved a higher mean score (118.5) than the control class (96.75). The median values also support this difference, with the experimental class scoring 118.5 compared to 95.5 in the control class. The smaller variance (56.4) and standard deviation (7.51) in the experimental group indicate that students' self-regulated learning levels were more consistent after the treatment, whereas the control group showed greater variability (variance = 138.47; SD = 11.77). The range of scores in the experimental class (24.0) was narrower than that of the control class (41.0), suggesting more stable results among students who received the intervention. Both groups displayed nearly normal distributions, with skewness values close to zero and slightly negative kurtosis, indicating relatively flat but symmetrical score distributions. Overall, the data indicate that the experimental treatment produced a positive effect on students' self-regulated learning, resulting in higher and more consistent performance compared to the control group.

Before doing statistical test, the data need to be transformed first from ordinal scale to interval scale using Method of Successive Interval (MSI). The data was transformed with the help of Microsoft Excel. The result of self-regulated learning questionnaire after transformation can be seen in Table 8.

Table 8: The Result of Self-Regulated Learning Questionnaire (Transformed)

Class	Means	Median	Variance	Std. deviation	Min.	Max	Range	IQR	Skw.	Kurt.
Experiment	711.57	711.72	76.4	8.74	698.52	726.64	28.12	15.53	0.089	-1.11
Control	695.77	711.74	4224.09	64.99	468.89	737.71	268.81	29.71	-3.2	11.18

The experimental group shows a mean score of 711.57 and a median of 711.72, indicating that the data are fairly symmetrical and consistent, as the mean and median are almost identical. The variance (76.4) and standard deviation (8.74) are quite small, suggesting that the scores are tightly clustered around the mean. The minimum score is 698.52, while the maximum is 726.64, producing a range of 28.12 and an interquartile range (IQR) of 15.53. The skewness (0.089) indicates a nearly symmetrical distribution, and the kurtosis (-1.11) shows a slightly platykurtic (flatter) distribution compared to the normal curve. This suggests that most students in the experimental group had relatively similar levels of self-regulated learning. In contrast, the control group has a mean of 695.77 and a median of 711.74, showing some inconsistency between the central tendency measures. The variance (4224.09) and standard deviation (64.99) are much higher than those of the experimental group, indicating a wide dispersion of scores. The minimum and maximum values (468.89 and 737.71, respectively) result in a range of 268.81, which is also much larger. The IQR (29.71) confirms greater variability among participants. The skewness (-3.2) indicates a highly negatively skewed distribution (scores concentrated on the higher end), while the kurtosis (11.18) indicates a leptokurtic distribution—very peaked, with many scores near the mean and heavy tails. Overall, the experimental group's results are more stable, consistent, and normally distributed, while the control group's scores show greater variability and non-normality. This pattern suggests that the experimental treatment may have contributed to more uniform and possibly improved self-regulated learning behaviors among students. Furthermore, based on the indicators, the result of the mathematical problem solving posttest can be seen in Table 9.

Table 9: The Result of Self-Regulated Learning Questionnaire Based on Indicators

Class	Means	Median	Variance	Std. deviation	Min.	Max	Range	IQR	Skw.	Kurt.
				Goal setting						
Experiment	141.92	141.7	1.58	1.26	140.75	144.49	3.74	2.11	1.101	0.32
Control	144.7	145.86	36.87	6.07	122.3	148.66	26.36	2.34	-3.78	14.78
				Task strategies						
Experiment	141.59	141.45	2.27	1.51	138.86	144.49	5.63	1.4	0.5	0.47
Control	139.22	145.85	359.21	18.95	75.25	150.05	74.8	3.06	-2.97	9.39
				Time management						
Experiment	144.34	145.88	7.58	2.75	139.81	147.29	7.48	5.22	-0.44	-1.58
Control	145.02	146.08	48.62	6.97	119.98	150.04	30.06	3.18	-3.44	12.93
				Help seeking						
Experiment	141.59	141.7	7.52	2.74	136.97	146.33	9.36	3.16	0.32	-0.35
Control	132.58	143.27	364.31	19.09	95.02	147.26	52.24	24.82	-1.17	-0.16
				Self-evaluation						
Experiment	142.12	142.4	5.94	2.44	137.91	145.89	7.98	4.44	-0.26	-1.14
Control	134.25	140.75	497.12	22.3	54.01	147.29	93.28	6.7	-3.53	13.05

In goal setting, the experimental group shows a mean score of 141.92, slightly lower than the control group (144.7). However, the variance (1.58) and standard deviation (1.26) in the experimental group are extremely low compared to the control group (variance = 36.87, SD = 6.07). This indicates that students in the experimental group exhibited more consistent goal-setting behaviors, while the control group showed greater variability. The skewness value of 1.101 for the experimental group suggests a mild positive skew (scores slightly concentrated below the mean), whereas the control group's skewness of –3.78 shows a strong negative skew, meaning most control students scored at the higher end but with wide dispersion. The experimental group also demonstrated a more normal and stable pattern (kurtosis = 0.32), while the control group distribution was highly peaked (kurtosis = 14.78), indicating extreme scores.

Task strategies, the experimental group's mean (141.59) is slightly higher than the control group's (139.22), indicating marginally better use of task-related learning strategies among experimental students. The variance and SD are again far smaller in the experimental group (variance = 2.27, SD = 1.51) compared to the control (variance = 359.21, SD = 18.95), showing that the experimental group's responses were much more consistent. Both groups show near-normal distributions, but the control group's skewness (–2.97) and kurtosis (9.39) again reflect non-normality and concentration of high scores, suggesting uneven application of learning strategies among control students.

Time management, the experimental class obtained a mean of 144.34, nearly equal to the control class's mean (145.02). However, the dispersion differs notably: the experimental group's SD (2.75) is much smaller than the control group's (6.97), showing that experimental students managed their time more consistently. The slight negative skew (–0.44) and kurtosis (–1.58) in the experimental class indicate a nearly symmetrical and relatively flat distribution, while the control group shows greater variability and peakedness (skew = –3.44, kurtosis = 12.93). This suggests that while some control students managed time effectively.

In the help-seeking dimension, the experimental group achieved a much higher mean (141.59) compared to the control group (132.58), showing that the experimental treatment encouraged students to seek help more actively when facing learning difficulties. The standard deviation for the experimental group (2.74) is again much smaller than that of the control (19.09), indicating that help-seeking behaviors were more uniform and balanced among experimental students. The distribution is nearly symmetrical for the experimental class (skew = 0.32), whereas the control class is negatively skewed (–1.17) with high kurtosis (–0.16), suggesting wide disparity in help-seeking tendencies.

For self-evaluation, the experimental group (M = 142.12) scored higher than the control group (M = 134.25). The variance (5.94) and SD (2.44) in the experimental class are considerably lower than in the control class (variance = 497.12, SD = 22.3), meaning the experimental group's ability to reflect and assess their learning was more consistent. The control group again shows extreme variability and non-normality (skew = –3.53, kurtosis = 13.05). The experimental distribution, with mild skewness (–0.26) and kurtosis (–1.14), suggests a balanced and stable pattern of self-reflection among learners.

Across all five indicators, the experimental group consistently demonstrates smaller variances and standard deviations, indicating greater consistency and stability in self-regulated learning behaviors. The control group displays wider score dispersion and non-normal distributions, implying inconsistent application of self-regulation learning. Although the mean differences between groups are not always large, the experimental group's homogeneity and balance across indicators suggest that the intervention or treatment effectively strengthened students' ability to regulate their learning—particularly in help-seeking and self-evaluation, which are crucial for independent learning and continuous improvement.

The result of the normality, homogeneity, means comparison test can be seen in Table 10.

The analysis shows that for overall self-regulated learning the experimental group's data passed normality (p = 0.607) while the control group did not (p = 0.000), and variance homogeneity was rejected (p = 0.031). The Mann–Whitney U test yielded p = 0.696, indicating no significant difference between experimental and control for that broad measure. In contrast, for the goal-setting dimension both groups failed normality (Experiment p = 0.006, Control p = 0.000), homogeneity was accepted (p = 0.183), and Mann–Whitney U was highly significant (p = 0.000) — indicating the intervention did produce a difference in goal setting. The task-strategies dimension saw the experimental group pass normality (p = 0.401) while control did not (p = 0.000), homogeneity was rejected (p = 0.005), and Mann–Whitney U was significant (p = 0.003) — again showing an effect. However, time management, help seeking, and self-evaluation each failed to show statistical significance in the Mann–Whitney test (p = 0.224; 0.780; 0.094 respectively), meaning no detectable difference for those dimensions.

Table 10: The Result of Normality, Homogeneity and Effectivity Test of LIT to Students' Self-Regulated Learning

Aspect	Test	Class	Significance	Conclusion
Self-regulated learning	Normality	Experiment	0.607	Normal
		Control	0.000	Not normal
	Homogeneity		0.031	Not homogen
	Effectivity (Mann-Whitney U test)		0.696	There is no difference
Goal setting	Normality	Experiment	0.006	Not normal
		Control	0.000	Not normal
	Homogeneity		0.183	Homogen
	Effectivity (Mann-Whitney U test)		0.000	There is difference
Task strategies	Normality	Experiment	0.401	Normal
		Control	0.000	Not normal
	Homogeneity		0.005	Not homogen
	Effectivity (Mann-Whitney U test)		0.003	There is difference
Time management	Normality	Experiment	0.009	Not normal
		Control	0.000	Not normal
	Homogeneity		0.459	Homogen
	Effectivity (Mann-Whitney U test)		0.224	There is no difference
Help seeking	Normality	Experiment	0.405	Normal
		Control	0.001	Not normal
	Homogeneity		0.000	Not homogen
	Effectivity (Mann-Whitney U test)		0.780	There is no difference
Self-evaluation	Normality	Experiment	0.340	Normal
		Control	0.000	Not normal
	Homogeneity		0.043	Not homogen
	Effectivity (Mann-Whitney U test)		0.094	There is no difference

These results align with broader SRL (self-regulated learning) literature in several ways. Meta-analytic evidence indicates that interventions promoting SRL tend to yield moderate positive effects overall in online and blended settings (23) specifically, components such as goal-setting and strategy use (planning, monitoring, selecting strategies) are among the earlier phases of SRL models and thus more amenable to change via intervention (24). The finding that goal setting and task strategies improved (while time management, help seeking, and self-evaluation did not) is consistent with research showing that behavioral regulation and reflective processes often require longer duration, stronger scaffolding, or more context change to produce measurable effects (25).

For goal-setting, the significant difference suggests the intervention successfully engaged students in setting intentional, actionable goals and thus improved their forethought phase of SRL. Interventions that include explicit goal-setting prompts and strategic planning support tend to yield improved student self-regulation and performance (26). PMC The same seems true for task strategies—the improvement here indicates students in the experimental class were better able to translate goals into concrete tasks (strategy selection, monitoring) compared to control.

Conversely, for time management, help seeking, and self-evaluation, the absence of significant effects suggests either the intervention did not sufficiently target those dimensions or the students did not gain skill transfer into those domains within the timeframe studied. Research on SRL shows that time-management skills — which involve scheduling, allocation of resources, persistence, and dealing with distractions — are more resistant to change and may need sustained training (27). Similarly, help-seeking, a social resource-management regulation strategy, often depends on learning culture, peer norms, and instructor support; without these scaffolds, differences may not emerge. And self-evaluation, part of the reflection phase of SRL, is usually considered the most advanced and slower to change (28).

In sum, the pattern of results suggests the intervention was partially effective: it improved the forethought and performance phases of self-regulated learning (goal setting, task strategies) but did not yet produce measurable changes in resource-management (time) or reflection phases (help-seeking, self-evaluation). For future work, this implies that to achieve fuller development of SRL, interventions should explicitly incorporate modules on time-management strategies (e.g., scheduling, monitoring), structured peer/instructor help-seeking opportunities, and guided reflective practices (e.g., self-evaluation prompts, feedback loops).

Conclusion

Based on the result, it can be concluded that the Local Instructional Theory (LIT) based on Realistic Mathematics Education (RME) on Definite Integrals learning for prospective mathematics teachers is effective to improve their mathematical problem-solving skills. This significant effect is because of the LIT consist of contextual problems, use mathematization models, use production and construction, use interactivity, and are interconnected. Furthermore, not only mathematical problem-solving skills, the LIT is also effective to improve all of the aspect of mathematical problem-solving skills, namely understand the problem, devise a plan, carry out the plan, and look back. For the self-regulated learning, although the descriptive statistics show differences in mean scores, but the compare means test indicates that these differences are not statistically significant. The reasons behind this, likely due to the outside factor of treatment and a limited sample size. Consequently, the observed mean differences may reflect random variation rather than a true effect. Nevertheless, there is significant effect of using LIT based on RME on prospective mathematics teachers' goal setting and task strategies.

The findings imply that LIT based on RME can be meaningfully implemented in teacher education programs to strengthen conceptual understanding and problem-solving competence. However, the limited impact on overall self-regulated learning indicates that RME-oriented LIT alone may not sufficiently support all aspects of self-regulation, despite its positive influence on goal setting and task strategies. Therefore, integrating explicit metacognitive supports within the LIT framework is recommended to promote more comprehensive self-regulated learning outcomes.

Abbreviations

LIT: Local Instructional Theory, RME: Realistic Mathematics Education, SRL: Self-Regulated Learning.

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Author Contributions

Christina Khaidirconceptualization, methodology, investigation, resources, writing the original draft, reviewing and editing, visualization, project administration, Ahmad Fauzan: conceptualization, methodology, validation, investigation, writing the original draft, reviewing and editing, supervision, funding acquisition, Arnellis: conceptualization, methodology, formal analysis, writing the original draft, reviewing and editing, Mega Iswari: validation, investigation, writing the original draft, reviewing and editing, visualization, supervision, Syafriandi: validation, investigation, visualization.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics Approval

Not applicable.

Declaration of Artificial Intelligence (AI) Assistance

Authors utilized generative artificial intelligence (ChatGPT) for language refinement; format modification; and structural editing purposes only. All legal analyses; data interpretations; and original content were developed by authors without AI involvement. Authors reviewed and verified all AI assisted development to confirm accuracy; maintain integrity; and adhere to all applicable academic and ethical standards.

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