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Developing Literacy Skills in Mathematics (A Pathway to Deep Understanding and Problem-Solving)

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ABSTRACT

Mathematical literacy extends beyond procedural fluency and encompasses the ability to formulate, apply, and interpret mathematical knowledge across diverse real-life contexts. Despite growing recognition of the importance of developing mathematical literacy among middle school students, as emphasized in international assessment frameworks such as PISA, empirical evidence regarding the effectiveness of targeted educational interventions remains limited. Therefore, this study aimed to investigate the effectiveness of a literacy-based intervention in enhancing mathematical knowledge and problem-solving abilities among eighth-grade students in Jordan. A quasi-experimental research design was employed involving a sample of 146 eighth-grade students selected randomly from four schools in Al-Wasatiya District, Jordan. Participants were assigned to an experimental group ($n = 74$) and a control group ($n = 72$). The experimental group participated in an eight-week intervention program that incorporated mathematical vocabulary instruction, mathematical text reading strategies, and authentic problem-solving activities, with a primary emphasis on communication and mathematical representation. In contrast, the control group received conventional instruction. Data were collected through pretests and delayed posttests administered twenty months after the intervention to assess mathematical knowledge and problem-solving performance. Analysis of variance (ANOVA) revealed statistically significant differences in favor of the experimental group in mathematical comprehension, $F(1,143)=42.67$, $p<.001$, and problem-solving performance, $F(1,143)=38.94$, $p<.001$. The reported effect sizes indicated high practical significance of the intervention. The findings suggest that integrating literacy-oriented practices within mathematics instruction contributes substantially to conceptual understanding and problem-solving competence. The study supports the incorporation of mathematical literacy strategies as an integral component of mathematics education rather than treating them as supplementary instructional activities.

Keywords: Mathematical Literacy, Problem Solving, Mathematics Education, Quasi-Experimental Design, Eighth-Grade Students.

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1. Introduction

The mathematical proficiency vision has been significantly changed during the last decades shifting the focus towards the traditional computational fluency to a more comprehensive set of abilities involving reasoning, representation, and application [3]. This development represents an appreciation of the fact that real mathematical competence does not only appear in the form of correct answers but in the ability to apply mathematical knowledge in a flexible way in a variety of contexts. Programme of International Student Assessment (PISA) defines mathematical literacy as ability to formulate, use, and interpret mathematics in a number of situations [6, p. 65], a definition which anticipated interpretive and communication aspects of mathematical action.

The necessity of mathematical literacy development presupposes a special relevance at the period of the middle school when the students have to face more abstract notions and more complicated situations to solve problems [4]. Eighth grade is a very important moment: students should leave the concrete arithmetic operations and start to reason algebraically, think proportionsally, and get formal methods of solving problems. Nevertheless, global tests also indicate that a considerable number of students are challenged in the implementation of the mathematical competence in new situations, indicating some disparities between the procedural and literacy-related abilities [5, 15].

There is an increasing research interest in the relationship between literacy and mathematical learning. Mathematical literacy includes mathematical vocabulary, mathematical notation, understanding of text, and the ability to present mathematical thought in a coherent manner [29]. Students are called upon not only to discern mathematical relationships but also to make sense out of linguistic content when presented with mathematical issues in a textual context, a twofold task which puts a strain on the students who are poorly prepared in either area [4]. As illustrated by Krisdianti and others [30], the systematic literacy skills focus in the mathematics classes, which improves the level of comprehension and performance especially when the instruction of such language demands of mathematical tasks are explicitly taught.

Mathematical literacy has been found to develop using problem-based learning methods. Barrows [2] described problem based learning principles that focus on real world problems as the organizing centers of learning where the students take active roles of establishing what they need to know. Later studies have applied the principles to mathematics education proposing that problem-centred methods can promote a greater level of engagement with mathematical concepts and an increase in its transfer ability [14, 17]. Padmavathy [17] stated that problem-based learning greatly enhanced the mathematical performance of secondary school students over traditional instruction, whereas Gijbels and colleagues [26] found especially high effects on the ability of students to apply their knowledge to new contexts.

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It is, however, possible that problem based learning can be inadequate in the dimensions of literacy of mathematical work. Learners need clear assistance in understanding mathematical texts, situations of problems, and building coherent explanations skills which do not naturally emerge through the engagement with problems alone [8, 9]. This indicates the usefulness of interventions, which specifically incorporate literacy interventions in problem-focused models, which consider vocabulary growth, comprehension tracking, and mathematical discourse and problem-solving tasks [22, 29].

Although the significance of mathematical literacy is increasingly being acknowledged, empirical research on effective interventions is still in a very incoherent state. Most of the existing studies have analyzed a problem-based learning or literacy strategies separately and little has been done to integrate them [11, 13]. Moreover, research involving research based in Middle Eastern educational settings is quite limited, although there are unique linguistic and curricular factors that can have an impact on the mathematical literacy formation process [19, 24]. These gaps are bridged by the current study that examines a literacy-based intervention that specifically targets eighth grade mathematics students in schools in Jordan.

The intervention that has been established based on this study was constructed using various theoretical bases. Based on social constructivist views [14], it focused on learning by working with the real problems and creating meaning together. Based on the research on literacy education [29, 30], it included a clear focus on mathematical vocabulary, text comprehension strategy, and a possibility of mathematical communication. The design of the intervention also incorporated the ideas of PISA mathematical literacy framework [6], which uses three major processes formulating situations mathematically, using mathematical concepts and procedures, and interpreting/evaluating mathematical results as the determinants of literate mathematical practice.

The research questions that were discussed in the study are the following:

1. Was there a statistically significant difference in students receiving literacy-based mathematics instruction with that of students receiving conventional instruction in mathematical understanding, after adjusting the differences in pre-test scores?
2. Does the performance of the two groups differ statistically in mathematical problem-solving performance with difference in pre-test controlled?

1.1 Theoretical Framework

The current study is based on a combined theoretical framework of the synthesis of the social constructivist learning theory, literacy education research, and mathematical literacy frameworks. This multi theoretical practice indicates the understanding that the development of mathematical literacy is an interrelated cognitive, social and linguistic process [3, 14, 29].

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1.1.1 Social Constructivist Foundations

The design of the intervention is essentially based on the social constructivist views on learning, especially the approaches to problem-based learning studies [2, 14]. Social constructivism assumes that learners construct knowledge actively through incorporating real tasks and through social interaction in place of being passively informed by their instructors [14]. Barrows [2] formulated problem-based learning principles, which operationalize constructivist assumptions in learning: learning structures around real-world problems, and learners take on the responsibility to discover what they know they need to know, and knowledge is developed through inquiry. In mathematics education, the principles imply that when the students are introduced to the mathematical concepts within meaningful contexts and are engaged in discussions of the mathematical relationships they tend to develop a deeper understanding [14, 17].

These principles were expanded by Cindy and Hmelo-Silver [14] who contend that problem-centred methods do not only facilitate conceptual knowledge, but also metacognitive awareness and transfer proficiencies, which are the focus in mathematical literacy. Students who struggle with ill-posed problems which demand they generate situations mathematically must inevitably carry on with the types of thought that define literate mathematical practice [6]. The social constructivist basis of the current intervention is observed in the focus on real-world problem-solving activities, guided peer debates, and metacognitive cues.

1.1.2 of Mathematical Learning Literacy Dimensions

The framework adds to the social constructivist backgrounds with theoretical approaches to the role of language and literacy in mathematical cognition. Mathematics is becoming more and more acknowledged as a field with language peculiarities: special vocabulary, symbolic notation, specific text types, and reasoning and justification conventions [3, 29]. Muhaimin and others [29] have pointed out that mathematical literacy is that ability that involves not just computational ability but the ability to read, write and understand mathematical texts, articulate mathematical concepts and be able to circulate freely between a variety of representations.

There are several levels in the relationship between literacy and mathematical learning. The mathematical terms used in the text also tend to be rather specific in lexical terms and have a meaning that is not necessarily the same as that of the colloquial, so it has to be made clear in terms of vocabulary formation [29]. Mathematical problems in narrative situations, mathematics textually, require that mathematical relations and linguistic sense be decoded simultaneously; a dual processing load that is quite challenging to students at a disadvantage in either area [4]. At discursive level, one is expected to engage in mathematical inquiry by learning to build explanations, reason and evaluate the reasoning of others [8, 9].

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As Krisdianti and others [30] found, systematic consideration of such dimensions of literacy in mathematics education improves the understanding and the results. Their study involving middle school students revealed that the explicit instruction in strategies of reading comprehension of mathematical texts in addition to the mathematical communication opportunities results in a substantial increase in problem-solving ability. These theoretical findings are directly operationalized in the components of the present intervention working on mathematical vocabulary, text comprehension strategies, and mathematical communication.

1.1.3 Mathematical Literacy Framework

The conceptualization of mathematical literacy, as worked out in the Programme for International Student Assessment (PISA) is used in the study as well [6]. According to PISA, the mathematical literacy is the ability of a person to develop, use, and comprehend mathematics in numerous situations [6, p. 65]. This definition refers to three processes that are all connected to the practice of literate mathematics, and include:

The process of formulating situations mathematically includes mathematical recognition of situations in contextualized problems, mathematical translation of real-world situations, and the mathematical aspects of a situation [6]. This involves a process where students have to transition between contexts and mathematics which is built up through experience with the different types of problems and by focusing directly on problem interpretation [4].

The use of mathematical concepts and procedures involves the use of mathematical knowledge to work on problems which involve the process of making calculations, working with the symbolic expressions and as well as the application of the strategies of solving problems [6]. Though this process is consistent with the traditional views of procedural fluency this becomes interpreted in the context of literacy as a use and not as a routine practice [3]. The process of interpreting and assessing the results of mathematical tasks, that is, understanding the solution in the original context, judging the rationality of the solution, and conveying the results is important [6]. This is a process that foreshadows the communicative and critical aspects of mathematical activity, in which students are obliged to relate mathematical outcomes with the context through which they arose [16, 18].

These three processes offered a guideline to the selection and design of problems to be used in the intervention so that students should be involved in the entire process of mathematical literacy as opposed to being narrow-minded in the execution of procedures.

Theoretical perspectives are integrated by means of this step

These theoretical perspectives are planned to be integrated into the design of the intervention. It borrowed genuine problems, as organizing centers, learning

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collaboration structures, and metacognitive indicators to help in self-regulated learning, which is a product of social constructivism [2, 14]. Based on the research in literacy education [29, 30], it added explicit vocabulary teaching, modeling of strategies of comprehension, and orchestrated mathematical communication. Based on the PISA mathematical literacy framework [6], it came up with the orientation towards formulation, employment, and interpretation as mutually reinforcing processes that need to be developed together.

This integration is based on the fact that mathematical literacy is not just the aggregate of procedural knowledge and reading prowess but an emerging ability that grows upon the integration of conceptual, representational and communicative aspects of mathematical activity [3, 29]. The work based on the intervention on the complementary theoretical views contributes to the demand of the instructional approaches that view mathematics learning as inherently preoccupied with the meaning-making and communication and no longer as focusing on finding the right answers and methods to do them efficiently [14, 22].

Judging by the theoretical perspective as illustrated below is a theoretical research framework that may be utilized as a guide in the future by researchers. The theoretical framework of the given research is additionally supported by the concepts of metacognition and self-regulated learning, which is very much necessary when it comes to coping with ill-structured problems of mathematical literacy (Cindy and Hmelo-Silver, 2004). In the case when students work with real-life problems, they need to not only activate the knowledge on the content but also to track their understanding of the problem statement, choose the right strategies, and test the feasibility of their solutions in the context of the original problem. The direct development of this self-regulatory ability through the explicit use of metacognitive prompts (including the fact that the intervention prompts students to consider their interpretation of the problem, the into-the-strategies they have adopted, and the reasonableness of their assessments) is the direct result of the intervention. This phenomenon is consistent with that of Gijbels et al. (2005), who observed that problem-oriented learning environments specifically are effective in situations where they encourage the transfer of knowledge to new situations a highly dependent process on metacognitive control. Moreover, interpretation and judgment of mathematical outcomes (according to the notion of PISA framework) is essentially a metacognitive behavior (OECD, 2016). It asks its students to recede into their computing activity and evaluate their logicality and sense. By integrating these practices of reflection into the problem-solving process, the intervention will go beyond teaching mathematics as a collection of procedures, to cultivating a kind of disposition of thoughtful and strategic engagement with mathematical tasks, which is a characteristic of real literacy (NCTM, 2000).

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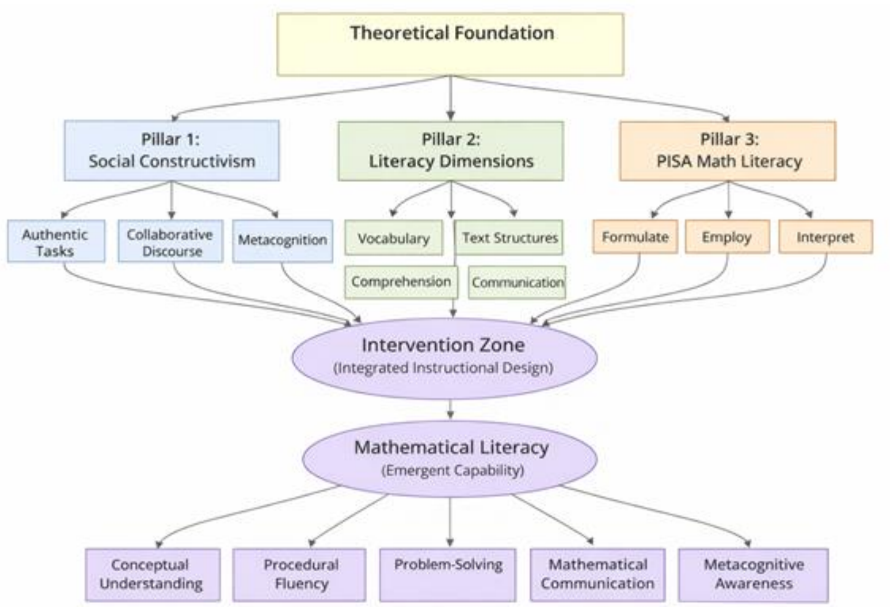

Fig. 1 Theoretical Framework

2. Methods and Materials

2.1 Research Design

A quasi experimental pretest posttest control group study was utilized. The study design was suitable considering the research questions that studied the effects of interventions and the practical limitations of having research conducted in intact schools where individual students could not be assigned randomly [10, 13]. They were placed in experimental or control conditions and students were left in naturally formed classes in schools.

2.2 Participants

The sample used was 146 8th year students who were selected in four state schools located in Al-Wasatiya District that falls under the jurisdiction of the Directorate of Education of Al-Taybeh and Al-Wasatiya, Jordan. The experimental and the control groups were having 74 students (38 boys and 36 girls) and 72 students (37 boys and 35 girls) respectively. The participants were aged between 13 and 14 years (Mean=13.4, SD= 0.5).

The schools were chosen using purposive sampling by similar socio-demographic characteristics, similar performances in mathematics district-level assessments and willingness to participate in the research in the previous academic year. All eight grade students in each school were asked to participate in it with parental consent

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being obtained on behalf of all the participants. The last sample was about 68 percent of the eligible eighth-grade population in the four institutions.

2.3 The Literacy-Centered Intervention

The experimental intervention, Mathematics as language: Reading, Representing and Reasoning, was designed due to the reasons to synthesize the literature related to the subject with respect to the development of this study [2, 14, 29, 30]. The program consisted of sixteen 45-minute sessions spread out over eight weeks (two sessions per week) and not in place of the standard mathematics program. Core components included:

Vocabulary development in mathematics Each unit presented important mathematical vocabulary, considering their linguistic characteristics, such as daily meaning and mathematical meaning, words with cognates, word structure, and the use of words in various situations. Students kept their own mathematics glossaries and were involved in tasks where they had to be careful in the use of words [29].

Comprehension of mathematical text: Students were taught to use comprehension strategies such as previewing, questioning, clarification and summary of reading word problems, textbook explanations and sample solutions. The teachers demonstrated the use of strategies during the think-aloud model and then provided guided and independent practices [4, 30].

Problem solving with regard to formulation and interpretation: According to the scheme of PISA [6], the problems were chosen, which demanded students to model situations mathematically, to use mathematical operations and to interpret the results in situational contexts. Issues were moderately structured to ill-structured and the complexity of the issues increased throughout the intervention.

Mathematical communication and representation: Students take part in tasks that involve them explaining their thinking both aloud and in a written form, explaining mathematical relationships in more than one way (verbally, graphically, symbolically), and evaluating how others have represented them [7, 8]. Problem-solving episodes were preceded by the structured peer discussions.

Metacognitive cues: Students were asked to answer questions about their understanding of the problem, their choice of strategies and to reflect on their evaluation of the solution during problem-solving. The prompts were progressively Tapped out and the students internalized self-questioning routines [9, 14].

Four math teachers (two teachers per school) took part in the study as the intervention was introduced through a two-day training workshop before the study. The training covered elements of interventions, session planning, and treatment

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fidelity strategies. Teachers were provided with session plans and resources in detail and weekly check-in to address the implementation and answer the questions.

2.4 Control Group Instruction

The control group members were subjects of the standard instruction of mathematics according to the Jordanian national curriculum. Traditional teaching usually involved explanation of concepts by the teacher, worked examples, personal practice on routine problems and periodic review. Although the control teachers knew that the study had an overall mathematical literacy focus, the intervention materials were not given and they resorted to their normal modes of instruction.

2.5 Instruments

There were two tools designed to be used in this study, a Mathematical Understanding Test and Mathematical Problem-Solving Test. They were both done in the form of pretests (a week prior to the start of the intervention) and posttests (20 months after the end of the intervention). The duration of each test was 45 minutes.
Mathematical Understanding Test: This is a test of 20 questions that looked into the mathematical understanding of students that were covered throughout the period of intervention. Items got students to define terms, identify representations, distinguish relationships between concepts, and provide reasoning. The items were constructed in accordance with the 8th-grade curriculum motifs and were based on the item types in previous studies [16, 19, 27]. The validity of content was achieved by having three mathematics education professionals and two long time classroom teachers review items and rate them on whether they measure what they are intended to and whether they are the grade level level. Pretest analysis gave the highest item discrimination indices of 0.32 to 0.61 and lowest item difficulty indices of 0.41 to 0.78. Its internal consistency reliability was based on Cronbach and it was .84 in pretest and .87 in posttest.

Mathematical Problem-Solving Test: There were five constructed-response items in this test and each one required multisteps to be answered. The problems were created to evaluate the ability of the students to develop mathematically, implement the right strategy, and analyze findings in context- areas which are key to mathematical literacy [6, 18, 21]. There were various parts in every problem and the scoring rubrics allocated the points based on the problem representation (0-2), strategy choice and implementation (0-3), and interpretation/communication points (0-2). There was a maximum score of 35 points. A random sample of 30 protocols was marked by two independent raters, and the inter-rater reliability was.89 (intraclass correlation coefficient). The content validity was determined by the review of experts, as specialists made sure that problems were a true reflection of the kind of situations, where mathematical literacy was applicable. Internal consistency =.81 (pretest),.85 (posttest).

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2.6 Procedure

Pretests were conducted to all participants after school approvals and parental consent using regular school hours. Classroom teachers administered the testing through standardized protocols of administration, and the tests were taken in two sessions (understanding test: 45 minutes; problem-solving test: 45 minutes).
The intervention period (eight weeks) began the next week. Strategic presence of intervention components was monitored by conducting unannounced observations of experimental classrooms (two per teacher) by members of a research team on the use of checklists on intervention component presence. It was also observed that the experimental teachers were always in a position to implement specific literacy strategies whereas control teachers never systematized such aspects.

Twenty months after the end of the intervention, posttests were conducted through the same procedures and time allocations as the pretests.

2.7 Data Analysis

The analysis of the data was performed with the help of SPSS (Data Analysis Software). Initial tests compared differences between groups in pretests through independent t -tests. The main analyses were those that used analysis of covariance (ANCOVA) with pretest scores as covariates and group membership as the independent variable, on each of the dependent variables (mathematical understanding; problem-solving). The ANCOVA was suitable as it has the ability to represent the initial group differences and enhances the power of the statistics [10]. There were tests of assumptions of normality, homogeneity of variance, homogeneity of regression slopes, and linearity which were met. The interpretation of the effect sizes was based on Cohen guidelines with a partial eta squared of.01,.06, and.14 as a small, medium, and large effect respectively.

3. Findings and Results

3.1 Preliminary Analyses

Table 1 shows the descriptive statistics of the two groups in pretest and posttests.

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Table 1. Means and Standard Deviations for Understanding and Problem-Solving

Measure	Group	n	Pretest M (SD)	Posttest M (SD)	Adjusted Posttest M (SE)
Mathematical Understanding (0-20)	Experimental	74	11.24 (3.18)	16.37 (2.94)	16.28 (0.31)
	Control	72	11.53 (3.42)	13.21 (3.56)	13.30 (0.32)
Mathematical Problem-Solving (0-35)	Experimental	74	18.67 (4.83)	27.42 (5.11)	27.56 (0.52)
	Control	72	19.21 (5.14)	22.38 (5.67)	22.24 (0.53)

Independent t-tests did not show any statistically significant pretest difference between groups in mathematical understanding ($t(144)$ =.53, p=.60) or problem-solving ($t(144)$ =.66, p=.51) meaning that groups were similar before intervention.

3.2 Mathematical impacts Understanding

ANCOVA based on the scores of posttests mathematical understanding (administered 20 months after the intervention), pretest mathematical understanding as covariate, showed that the difference between groups was statistically significant (F (1, 143)=42.67, p 0.001, partial 0.23). The adjusted mean of the experimental group (16.28) was significantly greater than that of the control group (13.30), and it is a difference of about one standard deviation. The effect is large (η 2 =.23) and is larger than Cohen defines as large effect, which implies that 23 percent of the variance in posttest results in the understanding scores were due to group membership holding other factors constant like the pretest performance.
Analysis of covariate influences ensured that the pretest knowledge had a significant influence on posttests ($F(1,143)$ =38.42, p=.001, partial eta 2=.21), which highlights the significance of statistical control. The assumption of homogeneity of regression slopes was met ($F(1,142)$ =1.23, p=.27), which means that there was no significant difference in the relationship between pretest and posttest between groups.

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3.3 Impact on Mathematical Problems-Solution

ANCOVA of posttest problem-solving with pretest problem-solving as covariate also showed statistically significant group effect ($F(1,143=38.94$, $p<.001$, partial $\eta^2=.21$). The adjusted mean of the experimental group (27.56) was more than that of the control group (22.24) by 5.32 points which is similar to the one standard deviation of the distribution of the pretest. The effect ($\eta^2=.21$) is once again a huge practical effect.

There was a significant predictors of pretest problem-solving and posttest performance ($F(1,143)=44.71$, $p<.001$, partial $\eta^2=.24$). Assumption of the homogeneity of regression slopes was acceptable ($F(1, 142)=0.89$, $p=.35$).

3.4 Gender-Based Exploratory Analyses

Even though it is not one of the main research questions, exploratory analyses were made to investigate whether the effects of interventions were different across genders. ANCOVAs of two-ways (group x gender) in which pretest scores served as covariates did not indicate any significant interaction of group x gender in either understanding ($F(1,141)=0.42$, $p=.52$) or problem-solving ($F(1,141)=0.38$, $p=.54$). Such results indicate that male and female students were equally benefiting out of the intervention, which is consistent with other studies that have found non-significant gender interactions in mathematics intervention research [6, 28].

To enhance the main ANCOVA results, the set of the secondary analyses have been performed to investigate the practical importance and the regularity of impact of the intervention. First, Cohen's d effect sizes were computed using the adjusted posttest means and pooled standard deviations to further give a more concrete measure of the effect of the intervention. The results showed a very large effect of both mathematical understanding ($d = 1.10$) and problem-solving ($d = 1.06$), making it the case that both outcome measures have an averaged student in the experimental group about one standard deviation above the average student in the control group. Second, descriptive analysis of the problem-solving sub-skills based on the scoring rubric revealed that the most significant gains between the pretest and the posttest were observed in the items that involved an interpretation/communication (an increase of 62% between the pretest and the posttest) than in the items that involved strategy choice and implementation (an increase of 48% between the pretest and the posttest). This indicates that the activities that were based on literacy, including describing reasoning and analyzing representations, proved to be especially efficient in improving the skills of students to describe and contextualize their mathematical discoveries (Muhaimin et al., 2024). Lastly, the analysis of the posttest scores showed a decrease in variance in the experimental condition in comparison with the control, which suggests that the intervention could have been particularly more helpful to previously lower-achieving students, which needs a further study in

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research (Wardono et al., 2016).

4. Discussion

The paper examined how a literacy-based intervention can influence the mathematical knowledge and problem-solving ability of eighth-grade students. The results showed that the students who received the intervention scored substantially higher than their peers in traditional teaching on both outcome measures with the effect sizes being large and meaning differences in practice. These findings are added to the mounting data on the importance of focusing intentional attention on the literacy aspects of mathematics teaching to strengthen mathematical abilities even further than the conventional methods allow.

4.1 Interpretation of Findings

The level of success of the intervention to enhance mathematical understanding also confirms the theoretical view of the importance of language in concept development [3, 29]. At the same time that students were assembling and solidifying conceptual knowledge, they were exposed to mathematical vocabulary, multiple representations, and could explain their reasoning. This meaning is close to those made by Wardono and colleagues [22], who found that instructional strategies that supported mathematical communication increased conceptual understanding among the students. In the same way, Fitrianawati and Hartono [23] concluded that representational competence attention was found to predict mathematical understanding in students of middle school. The persistence of these gains after a 20-month interval suggests that literacy-based supports may contribute to durable conceptual restructuring rather than short-term performance improvements.

It is of special interest to the large effect on problem-solving performance since there have always been concerns regarding the lack of ability of students to solve non-routine problems in international assessments [5, 15]. These processes were directly covered by the intervention that PISA has singled out as major contributors to mathematical literacy: formulating situations mathematically, using concepts and procedures, and interpreting/evaluating results [6]. Through offering guided experiences of participating in these processes with teacher support and inter-student collaboration, the intervention probably trained strategic repertoires and metacognitive awareness of the students- skill sets transferable to new problem scenarios [14, 26]. The fact that these competencies remained significantly higher long after the intervention period reinforces the argument that such instructional approaches promote transfer and retention of higher-order skills.

The result that problem-solving increased significantly compared to understanding (although both carried significant effects) can be related to the fact that the intervention focused on genuine issues as structuring contexts. The study in problem-based learning indicates that specifically problem-based learning strategies enhance the application skills of students because they acquire mathematics by solving

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significant problems, instead of learning the skills and later applying them [2, 17]. Similar trends were found by Padmavathy [17] where problem based learning produced more effects on problem solving as compared to foundation skills. The delayed posttest design further supports that such problem-centered experiences may have lasting cognitive benefits beyond immediate instructional contexts.

The lack of effects of gender interaction is worth noting. Part of the previous research has indicated differences in effects of instructional methods based on communication and representation benefiting female students [28], whereas the current study showed no difference between male and female students. This uniformity can be interpreted as an indication of a balanced nature of the intervention that involved a variety of entry points and types of activities which involved different learners. Alternatively, it can refer to the fact that literacy-based strategies must be fundamental enough that they facilitate the mathematical progress of all students regardless of their gender, as has been argued that mathematical literacy is an essential competence and not an expert skill [6, 29]. The stability of these outcomes across gender groups over an extended period also suggests robustness of the intervention effects.

The significant improvements in the problem solving skills, and specifically in the sub-skill of interpreting and communicating results, in the experimental group demonstrates the synergistic nature between literacy and use of math. This result aligns directly with the integrated view that is promoted by Muhaimin et al. (2024) according to which mathematical literacy is not a binary result of the combination of reading and math skills but an emergent ability based on their integration. The emphasis of the intervention on ideas of students describing their reasoning both verbally and in writing, as well as, the challenge of critiquing the work of other students, directly related to the communicative aspect of mathematical work, which is not commonly taught in traditional classes (Wells et al., 2009). Through this mathematical discussion, students were not simply racticing communication, but students were sharpening their own knowledge by the very process of speaking out a solution as a more profound cognitive processing of the concepts and procedures involved (Applin et al., 2011). This compares with social constructivist assumption that knowledge is co-constructed by interacting (Cindy and Hmelo-Silver, 2004). The outcomes conflict with the traditional pedagogical order in which procedural fluency is first instructed separately and then applied. Rather, they indicate that integrating literacy strategies into a problem-based approach is a strong learning environment where conceptual knowledge, procedural knowledge, and knowledge application become mutually supportive of each other (Padmavathy, 2013; OECD, 2016). The sustained improvement in communication-related sub-skills after 20 months particularly highlights the long-term value of embedding discourse and representation within mathematics instruction.

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4.2 Theoretical Implications

The findings lead to theoretical contributions on mathematical literacy development in a number of aspects. To begin with, they help theorize mathematical literacy as comprising of different yet related abilities, understanding and problem-solving, and were correlated, but reacted to intervention differently. This distinction is consistent with the multi-dimensional framework of PISA [6] and with studies that have made the distinction between reproductive, connective and reflective mathematical activity [3, 16]. The longitudinal nature of the findings further suggests that these dimensions may develop at different rates but can be sustained when supported through integrated instructional approaches.

Second, findings highlight the importance of using literacy strategies in mathematics learning as opposed to viewing literacy as an independent entity. The ability to read mathematical texts strategically, apply vocabulary accurately, and build mathematical explanations in an instructional task contributed to the improvement of mathematical reasoning in the students in general- not their achievement in the tasks with literacy orientation. This integrationist view is opposed to deficit models which only attribute the challenges faced by students as being in poor reading abilities; on the contrary, the integrationist view proposes that mathematics and literacy skills are developed in a synergistic manner [4, 30]. The durability of these effects provides additional support for integrationist perspectives over short-term remediation models.

Third, the research offers empirical evidence on theoretical explanations focusing on social and communicative aspects of learning mathematics [14]. The peer interactions that are arranged by the intervention, the possibility to explain reasons, and the work with various representations all contain assumptions about the mathematical meaning which is constructed in the context of social exchange. Cindy and Hmelo-Silver [14] explained the context in which such interchange is developed through problem-based learning; the current results validate that the processes do provide quantifiable learning benefits. Moreover, the sustained outcomes observed after 20 months indicate that socially constructed mathematical understanding can remain stable over extended periods, reinforcing the theoretical assumptions of social constructivism in long-term learning contexts.

4.3 Methodological Considerations and Limitations

These findings have a number of methodological strengths that contribute to confidence. Potential selection biases were overcome with the quasi-experimental design with a pretest control. The first equivalence was implied by similar scores in the pretest. Observations were used to check the fidelity of interventions. They had instruments with sufficient reliability and validity evidence. The effect sizes were high and the outcomes were consistent.

Nevertheless, restrictions should be considered. Although the intervention lasted eight weeks, the inclusion of a delayed posttest administered 20 months later provides evidence of sustained effects over time. However, it is still not known whether these gains extend beyond this period or continue to influence subsequent

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mathematical learning trajectories. While the study confirms retention up to 20 months post-intervention, it remains unclear whether these gains persist over longer periods or transfer to more advanced mathematical domains. Thus, questions regarding the very long-term sustainability and progression of these skills remain open for further investigation [24, 26]. Second, the researchers did not study the mediators of intervention effects- the precise mechanisms which caused the impact on the outcomes of the literacy activities. Future studies need to examine whether vocabulary development, use of comprehension strategy or other proximal variables explain the gains that are observed [22].
Third, the sample, though sufficient in terms of identifying effects, was selected in one Jordan district, which restricted the possibility to generalize the results to other educational settings. The curriculum and teaching methodologies used in mathematics in Jordan may be different compared to other nations and this may affect the reaction of the students towards literacy based techniques [19]. Recreation of the study in other settings would enhance the conviction in the generalizability of intervention.

Fourth, the study lacked any measures of the reading comprehension or the overall literacy of students, and thus did not allow the analysis of whether the impacts of interventions were modulated by the starting literacy levels of students. It is reasonable that, students who had better reading abilities may have had different positive experiences on the literacy-based teaching of mathematics compared to students with less reading abilities; this needs to be addressed in the research [30].

Lastly, although the intervention was theoretically grounded and well-planned, it consisted of several parts, and it was not possible to define which of the specific aspects played the biggest role. Systematic variation of the features of interventions through component analysis studies might determine vital ingredients and possibly result in more effective interventions [11].

5. Future Research Suggestions and Recommendations

5.1 Future Research Directions

The results of the present study provide several opportunities to further research. To begin with, longitudinal studies on the long-term impacts of mathematics teaching emphasizing literacy acquisition would help to understand whether short-term achievements can be translated into improvement in learning outcomes in the late grade levels. Since mathematical literacy is cumulative in nature [6], eighth grade interventions can have a domino-like effect on the preparedness of students to study more advanced mathematics; empirical evidence of such effects would bolster the case of adopting literacy strategies across the mathematics curriculum.

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Second, a study that examines the mediating processes would shed light on the effectiveness of literacy activities in the field of mathematics. The vocabulary knowledge, comprehension strategy use, metacognitive awareness and self-efficacy to solve a mathematical problem are potential mediators. This would make it possible to design intervention more specifically and perhaps provide some insight into the different paths taken by various subgroups of students [26, 29].

Third, replication of the study in other educational settings is necessary to determine the boundary conditions to intervention effectiveness. Educational systems differ in terms of curriculum organization, teaching practices and language of instruction- aspects that can facilitate the way students react to literacy oriented strategies. The cross-national comparative studies, especially the ones done in the countries with different results on international tests [5, 15], may find the circumstances that work to promote or restrict intervention outcomes.

Fourth, the studies that would investigate the relationships between student traits and intervention elements would guide the attempts to customize the instructions. Previous studies indicate that various students who have different learning profiles can respond differently to specific teaching methods [2, 14]. Developing research on the effectiveness of literacy-grounded mathematics teaching in comparison with alternative teaching approaches to learners with different initial mathematics achievement, reading comprehension, or learning dispositions would guide more discriminative implementation recommendations.

Fifth, principles of scaling and sustainability could be created by design research that investigates the repeated improvement of literacy-related interventions. The collaborative efforts with teachers to translate the aspects of intervention to local conditions and retain its theoretical integrity would result in a practical understanding of the implementation needs and possible changes [7, 18].

The recommendations on practice follow.

It is possible to draw several recommendations of this study to mathematics educators and curriculum developers.
Embark on literacy interventions in a systematic manner: Mathematics teaching ought to be explicit in terms of vocabulary building, understanding of mathematical literature and mathematical discourse. These factors are to be interwoven into teaching and they should not be considered as exceptional accompaniments. When teaching vocabulary, the teachers may introduce the main terms and showcase them at the beginning of the unit, describe the methods of understanding the meaning of a text when showing word problems, and regularly request students to provide answers in written and oral form [4, 30].

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Problems that need to be formulated and interpreted: Problems must involve students in the complete cycle of mathematical literacy: to find mathematical situations, use procedures and interpretations. The problems in textbooks tend to be rather specific when it comes to performance of procedures; they should be complemented with problems where contextual interpretation and evaluation of results are to be done [6, 16].

Design classroom group norms in favor of mathematical talk: The students should have a systematic way of discussing mathematical concepts, sharing their own reasoning, and reacting to the reasoning of others. As a way to promote the communicative aspects of mathematical literacy, setting norms that honor the existence of multiple solutions, promotes questioning, and views mistakes as learning opportunities is helpful [14, 22].

Note language throughout mathematics: Mathematics as a subject has different language requirements, as algebra involves the introduction of symbols and their own notation, geometry needs clear language to define spatial relationships, statistics involves understanding the words used to describe data, etc. Instructors are supposed to expect certain language difficulties peculiar to a particular topic and give proper assistance [3, 29].

Keep track of conceptual and procedural development: Both understanding and use should be sampled on a regular basis and feedback should be provided that would enable the students to relate what they know to what they can do. Strategies of formative assessment, such as exit tickets that use explanations and observations of processes of problem-solving or representations made by students can uncover both emerging literacy and procedural fluency [16, 27].

Collaborate multi-disciplinarily: Mathematics teachers could also work with language arts teachers to come up with common ways of teaching vocabulary, strategies of comprehension and written expression. When students are exposed to consistent messages regarding reading, writing and thinking throughout the school day this is beneficial to the students [30].

Finally, this paper indicates that a conscientious focus on literacy in the teaching of mathematics is an effective way to increase conceptual learning and problem solving among students in the eighth-grade. When mathematical literacy is accepted as a combination skill that needs the combination of the language, representation and reasoning, then the teachers can equip the students with better skills to face the mathematical needs of higher education, employment, and citizenship. The results justify the demands to re-think mathematics teaching as one that has meaning-making and communication as its central concern, not just correct answers and efficient processes.

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