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Designing and Implementation of Instructional Material to Enhance Critical Thinking and Problem-Solving Skills of Students

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Abstract

This study ascertained the levels of critical thinking and problem-solving skills of randomly selected 466 Grade 10 students and the least mastered critical thinking and problem-solving skills. The Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model was utilized in the skills assessments, designing the instructional materials, developing the instructional materials through a seminar-workshop, implementing the instructional materials, and evaluating the instructional materials. In the analysis phase, results show that the students' skills were initially in the "beginning" and "developing" stages, respectively, and the content areas where students had the least mastered skills were quadratic equations and inequalities and quadratic functions. The instructional materials were designed through a problem-based learning approach, then developed by teachers through a seminar-workshop. After the development of the instructional materials, it was then pilot tested in different schools. The last phase is the evaluation of another set of teachers, result of the evaluation shows that the modules enhanced the students' critical thinking and problem-solving skills and were rated "very good".

Keywords: critical thinking skills, problem-solving skills; K-12 mathematics curriculum; development of instructional materials.

INTRODUCTION

Mathematical performance has long been a major concern in the Philippines, as seen by national and international test results and studies. The Trends in International Mathematics and Science Study (TIMSS), which evaluates fourth and eighth-grade mathematics and science proficiency across a wide range of countries, cultures, and languages, shows the Philippines' poor performance in mathematics (Martin, et al. 2004). Even having science high schools participating, the Philippines scored 10th out of 10 countries in the 2008 TIMMS Advanced, which followed the same science and mathematics framework as the standard TIMMS (Mullis, et al., 2009). In terms of average scores and percentages of correct replies, this poor performance was also observed in specific content areas and cognitive domains (Ogena, Lana, and Sasota, 2010). After implementing the K-12 program, the Philippines participate in an international assessment of basic education. The PISA (Program for International Student Assessment) 2018 results are disturbing, with the Philippines ranking last (OECD, 2019).

The problem in learning mathematics is present not only among students in elementary and high school but also among those in college and even in prestigious schools and science high schools. The same problems are experienced by educators in mathematics and there is a need to study further their

competencies and teaching skills as well as to improve their teaching strategies and methods used in teaching. The situations do not only present mathematics as a subject with difficult concepts and processes but also show how students perform. This problem requires widespread implementation of well-planned intervention by everyone involved in the educational system. Something should be done and should start in the classroom. Teachers are the best instruments to make change happen. Many would agree that mathematics is not just a difficult subject to learn but a subject difficult to teach as well.

The only country in Asia with a 10–year basic education cycle until 2012 was the Philippines and the country is still far behind other countries in the world as far as development in terms of educational program implementation is concerned. Philippine basic education has shifted to 12–year cycle, the K–12 Curriculum, in June 2012 to become globally competitive. The study conducted by Crisol and Alamillo (2014) revealed that the majority of the students and teachers have positive attitudes toward the implementation of the program for they believe that the added years would provide them with ample knowledge and skills and would enable them to compete globally.

The situations do not only present mathematics as a subject with difficult concepts and processes but also show how students perform. This problem requires widespread implementation of well-planned intervention by everyone involved in the educational system.

The twin goals of the K-12 Mathematics Curriculum are the achievement of critical thinking and problem-solving skills of students. Hence, this study assessed the critical thinking and problem-solving skills of Grade 10 students in Patterns and Algebra. This assessment was expected to ascertain the content standards with the least mastered critical thinking and problem-solving skills of students and developed instructional materials for the development of these skills.

The K-12 Mathematics Curriculum

Mathematics is a subject that encompasses all aspects of life, regardless of age or condition, and hence has importance outside of the classroom. It is necessary to learn it thoroughly and thoroughly as a school subject. Critical thinking and problem-solving are the twin aim of K-12 Mathematics curriculum in the Philippines. Paul (1990) defines critical thinking as “the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and evaluating information gathered by observation, experience, reflection, reasoning, or communication as a guide to action”. Mathematical problem-solving, on the other hand, entails overcoming a challenge or obstacle and determining a solution to an unknown problem (Polya 1945; 1962). These two objectives will be met through a well-structured and rigorous curriculum, a well-defined set of high-level skills and procedures, acceptable values and attitudes, and appropriate instruments, all while taking into account the many circumstances. Numbers and Number Sense, Measurement, Geometry, Patterns and Algebra, and Probability and Statistics are the five core areas in the curriculum, as adapted from the framework produced by the Philippine Council of Mathematics Teacher Educators (MATHTED) and Science Education Institute in 2010. Knowing and understanding; estimating, computing, and solving; visualizing and modeling; representing and communicating; conjecturing, reasoning, proving, and decision making; and applying and connecting are the specific abilities and processes to be developed. Educators have recognized that manipulative objects, measuring equipment, calculators, computers, cellphones and tablet PCs, and the internet are all vital tools for teaching mathematics.

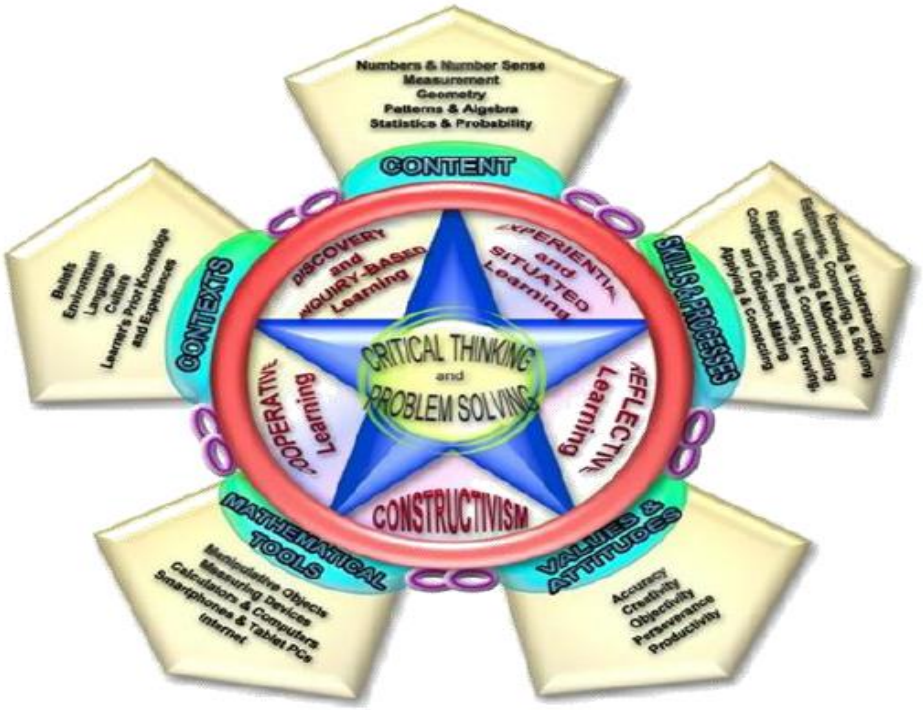


Figure 1. *Conceptual framework of K – 12 Curriculum.*

Methodology

The developmental research design was used in this study to determine the students' levels of critical thinking and problem-solving skills and the content standards with the students' least-mastered skills and developed instructional materials in Patterns and Algebra. According to Seels and Richey (1994), developmental research is "the systematic study of designing, developing and evaluating instructional programs, processes, and products that must meet the criteria of internal consistency and effectiveness". In its most basic form, developmental research can be the study of the process and impact of specific instructional design and development efforts; or a situation in which someone is performing instructional design, development, or evaluation activities while simultaneously studying the process; or the study of the instructional design, development, and evaluation process as a whole or of specific process components.

The study participants were 466 grade 10 students for critical thinking and problem-solving skills assessments. They were chosen through proportional stratified random sampling from one city school, one town school, one barangay school, and one private school.

Twenty-five secondary mathematics teachers participated in the seminar workshop for the development of the four problem-based learning modules. Students from four schools were participants in the pilot testing of the developed instructional materials. Twenty mathematics teachers (non-participants in the seminar workshop) evaluated the modules.

Researcher-made tests, content-validated and reliability tested, were utilized to gather data on students' critical thinking and problem-solving skills as well as their least mastered skills. The critical thinking skills test was based on the six cores of critical thinking (Facione, 2011). These critical thinking skills included interpretation, analysis, inference, evaluation, explanation, and self-regulation.

Problem-solving skills test on the other hand was based on the four dimensions of problem-solving (Wu and Adams, 2008). These dimensions are reading or extracting all information from the question; sense-making or real-life and common-sense approach to

solving problems; mathematics concepts, mathematization and reasoning; and standard and computational skills.

In phase 1 of the study, the researcher determined first the exact number of students in the target population needed for choosing the sample size, followed by the selection of participants using proportionate stratified random sampling. The researcher asked permission from the Department of Education as well as the principals and school heads of the chosen schools for administering the instruments. The researcher summarized the results and determined the levels of critical thinking and problem-solving skills. The researcher then determined the subject areas where the students had the least-mastered skills.

Phase 2 involved the development of the instructional materials. The overall ADDIE model is developed using five common components of instructional design, according to Seels and Glasgow (1998). The abbreviation ADDIE stands for Analysis, Design, Development, Implementation, and Evaluation, which are all aspects of the study. The ADDIE model is a systematic model, which represents a dynamic and flexible guideline for developing effective teaching and learning tools. Figure 2 summarizes the different activities in various phases. The analysis referred to the assessment of the student's critical thinking and problem-solving skills to identify the content standards with the students' least mastered skills. The following analysis was the Design of the problem-based modules to enhance students' least-mastered content standards. Next was the Development of the problem-based modules through a seminar-workshop in which the teachers and experts were invited to give suggestions on the module draft prepared by the researcher. After this development, the modules underwent Implementation through pilot testing. The last stage was the Evaluation of the developed modules by another set of teachers.

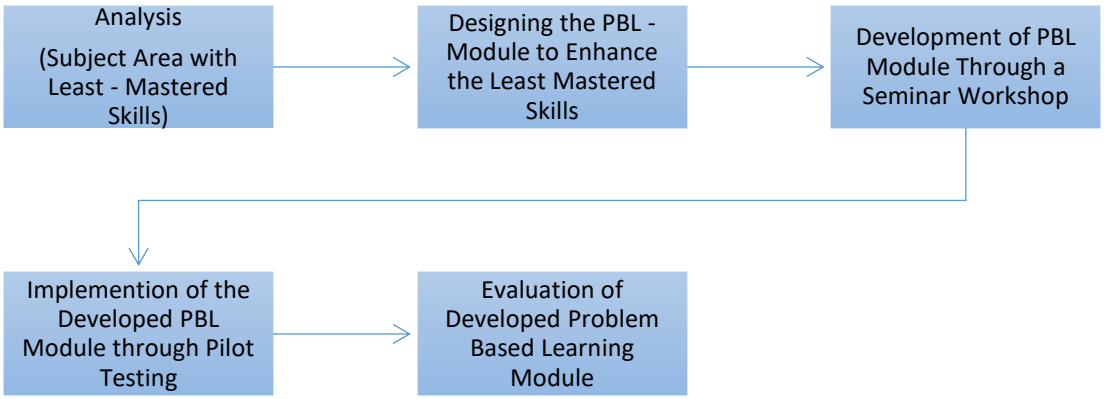


Figure 2. *The flow of the assessment, design, development, implementation, and evaluation of the Problem-based Learning Module.*

Results and Discussions

Analysis stage. Results showed that the student's critical thinking skills were at the "beginning" (M=7.87, SD=6.17) stage. On the other hand, the students' problem-solving skills were at the "developing" (M=11.91, SD=5.83) stage.

Table 1 *Mean Scores of Students in Critical Thinking and Problem-Solving Skills*

	N	*SD*	*M*	Interpretation
Critical Thinking Skills	466	6.17	7.87	Beginning
Problem-Solving Skills	466	5.83	11.91	Developing

Note: Interpretation is based on the following scale. Critical Thinking – accomplished (33.01 – 44); competent (22.01 – 33.00); developing (11.01 – 22.00); and beginning (0.00 – 11.00).

Problem Solving – accomplished (34.51-46), competent (23.01-34.50), developing (11.51-23.00), and beginning (0.00-11.50).

The content standards where the students had the least-mastered critical-thinking skills were Quadratic Equations and Inequalities and Quadratic Functions. The content standards where the students had least-mastered skills in problem-solving were also Quadratic Functions and Quadratic Equations and Inequalities. These results were the bases for the development of modules.

Table 2 *Number of Students Who Got the Correct Answers in Different Content Standards*

Content Standards	Critical Thinking Skills (*n* = 466)			Problem Solving Skills (*n* = 466)		
	frequency	percentage	rank	frequency	percentage	Rank
Algebraic expressions, properties of real numbers, and inequalities in one variable.	41	8.80%	10	167	34.55%	9
Special Products and Factors	33	7.01%	9	243	52.15%	11
Algebraic Expressions and Algebraic Expressions with Integral Exponents	24	5.15%	7	166	35.62%	7
Linear Inequalities in Two Variables	32	10.51%	11	136	29.18%	5
Systems of Linear Equations in Two Variables	49	6.87%	8	163	34.98%	8
Quadratic Equations and Inequalities	**8**	**1.72%**	**1**	**83**	**17.81%**	**2**
Quadratic Equations	**12**	**2.58%**	**2**	**54**	**11.59%**	**1**
Variations	19	4.10%	6	209	44.85%	10
Radicals	17	3.65%	5	97	20.82%	3
Sequences and Series	15	3.22%	3	134	28.76%	4
Polynomial function	16	3.43%	4	150	32.19%	6

Designing stage. The researcher utilized the problem-based approach in designing the instructional modules. In using this approach, teachers help students focus on solving problems in real-life contexts, encouraging them to consider the situation in which the problem exists when trying to find solutions. The majority of PBL research, according to Barrows (1996), has the following important features: collaborative small-group work, student-centered approach, teacher as facilitator, and utilization of real-life situations as the organizing emphasis. These crucial aspects were incorporated into the module design by the researcher. Students' successful knowledge management experiences aid them in solving mathematical issues (Boaler, 1998). Problem-based learning is a classroom technique that centers mathematics instruction on problem-solving tasks, giving students more opportunities to think critically, offer new ideas, and interact mathematically with their classmates (Lewellen & Mikusa, 1999; Erickson, 1999; Hiebert, et al., 1996; Hiebert, et al., 1997). Furthermore, as teachers take on increased tasks in addition to presenting

mathematical knowledge in PBL situations, their teaching talents become vital. In addition to learning core mathematics, students in PBL environments must study a variety of mathematical processes and abilities linked to communication, representation, modeling, and reasoning (Smith, 1998; Erickson, 1999; Lubienski, 1999). Both novices and experienced mathematics teachers face new problems in preparing teachers for their roles as supervisors of PBL environments (Lewellen & Mikusa, 1999).

IM Design Template

I. Title
II. Topic
III. Learning Objectives
IV. Introduction
V. Activity/Content/Activity
VI. Enrichment
VII. Experiences and Reflections
VIII. Self-Assessment
IX. Feedback

Figure 3. *Instructional materials design template.*

Development of Instructional Materials. A seminar workshop, conducted with teachers coming from different secondary schools, focused on the development of the designed problem-based learning modules. Specifically, the seminar-workshop aimed at (1) enhancing teachers' knowledge in problem-based learning and module making; (2) updating the secondary teachers concerning the results of the assessment of critical thinking and problem-solving skills of students; (3) sharing their experiences and strategies in teaching mathematics through focus group discussion; (4) developing the designed instructional modules to enhance the student's critical thinking and problem-solving skills.

The focus group discussion ended up on the following arguments: (1) Teachers use collaborative learning in mathematics teaching and enhance students' critical thinking and problem-solving skills through activities; (2) teachers give problems to measure students' critical thinking and problem-solving skills; (3) Department of Education learning material was insufficient, activities are redundant and boring, and content is wanting; and (4) omit some activities, include concept, arrange sections properly and systematically, and include examples.

Proceedings of the Seminar-Workshop

The seminar workshop was entitled "Seminar-Workshop on Problem-based Learning Module Development". It started with a registration followed by a short program during which the participants.

PROGRAMME

8:00 AM – 9:00 AM	Arrival and Registration
9:00 AM – 9:30 AM	Prayer
	Opening Remarks
	Introduction of Participants
9:30 AM – 10:00 AM	How to Make a Module?
10:00 AM – 10:30 AM	Problem-based Learning
10:30 AM – 12:30 PM	Focus Group Discussions
12:30 PM – 1:00 PM	LUNCH
1:00 PM – 3:00 PM	Workshop
3:00 PM – 4:30 PM	Presentation of Outputs/Synthesis

Figure 3. *Instructional materials design template.*

There were two speakers in the morning session who talked about "How to Make a Module?" and "Problem-based Learning".

The talk was followed by focus group discussions. The main purpose of the FGD was for the participants to share their experiences as well as their teaching strategies in enhancing students' critical thinking and problem-solving skills. Specifically, it sought answers to the following questions (1) What strategies did you use in teaching mathematics? How did these strategies increase the critical thinking and problem-solving skills of students? (2) How did you measure the critical thinking and problem-solving skills of students? What is your students' performance in mathematics? (3) What are the materials given by the DepEd? What can you say about the module in terms of its effectiveness? (4) What suggestions do you want to be included in the existing materials?

The researcher transcribed and identified the theme from the responses of the participants in the focus group discussions.

Collaborative learning as a teaching strategy. Collaborative learning is a teaching and learning strategy in which students work together to solve a problem or produce a meaningful project. "Collaborative learning," according to Smith & MacGregor (1992), is an umbrella word for a variety of educational methodologies including a shared intellectual endeavor by students or students and teachers. To obtain answers, solutions, or meanings, or to build a product, students frequently work in groups of two or more. Collaborative learning activities vary greatly, but the majority of them focus on students' exploration or application of course material rather than the teacher's presentation or explanation of it. The lecture/listening/note-taking process may not fully disappear in collaborative classrooms, but it coexists with other processes centered on student conversation and active work with course material.

Teacher A said that she used collaborative learning as a teaching strategy to enhance the critical thinking and problem-solving skills of students, "I used collaborative learning as a teaching strategy. Collaborative learning increases students' critical thinking and problem-solving skills. The students must share their knowledge, they could share their ideas if the activity that was given to them will be done by a small group and their answers will be shared with their classmates".

Teacher B added and supported by others "The skills of students may increase, depending on the activities given. If the activities are good, then they enjoy and they think critically". In this manner, teachers use collaborative learning and varied activities to enhance students' critical thinking and problem-solving skills. Students who acquire cooperative learning skills also grasp critical thinking skills. Small-group activities, according to Mansbach (2015), allow students to communicate, solve problems, hear other perspectives, and collaborate to assess and synthesize course information. Instructors can engage students in several levels of critical thinking by providing small-group exercises.

Giving task problems to assess, however, shows poor performance. The FGD revealed that teachers used task problems to assess students' critical thinking and problem-solving skills. Teacher C disclosed and was agreed by others: "We have given them problems, then if they can answer maybe they exhibit critical thinking and problem-solving skills. However, the performance of students was low".

The researcher showed the Phase 1 result of the study and asked them if the DepEd gave them the instrument in measuring critical thinking and problem-solving skills and showed an example of the dimensions of these skills. One of the participants answered, "That is the problem, if the goals of DepEd are critical thinking and problem-solving skills, then they should give the questionnaire the same as presented". Correct assessment tools are very important in achieving the goals of the K–12 Curriculum. Correct assessment tools influence students' evaluations of what is important to learn, their motivation and self-perceptions of ability, and the structure of their study approaches and timing... consolidate learning

and shape long-term learning techniques and skills (Crooks, 2009).

The module is the only instructional material given by DepEd. To improve the quality of their courses, teachers at all levels use a variety of instructional materials such as textbooks, presentations, modules, handouts, and so on. The quality of such resources has a direct impact on the quality of instruction. With the implementation of the K–12 curriculum, most of the teachers complained that they were given only the module. Teacher D asserted and was supported by other teachers that "The only learning material that DepEd provided was Learners' Module, it was not sufficient, since the module for Grade 7 is still not finished because only the module for the first quarter was only given". For the effectiveness of the Dep Ed module, Teacher E added, "The module is good, but the problem is that the activities are redundant, and boring for students, then there is no content, almost activities; content should be included".

Suggestions for inclusion in the development of instructional materials. Many suggested omitting some of the activities. Teacher F declared that "We should omit some of the activities and include the concept". Teacher F further suggested arranging the topics systematically and should include more examples. Teacher G said that "The module should be arranged properly and cite some examples since not all students are in the higher sections".

The afternoon sessions were devoted to the workshop proper. The participants (20 secondary mathematics teachers) were grouped into four. The researcher gave the 4 designed modules to the participants. Group 1 developed Module 1, group 2 for Module 2, group 3 for Module 3, and group 4 for Module 4. Then each of the groups presented and shared their output. All comments, suggestions, and recommendations in the workshops were integrated into the developed instructional materials.

Four modules were developed. These are the following:

1. Module 1: Quadratic Equations, with four lessons

Lesson 1: Solving Quadratic Equations by Extracting Square Root

Lesson 2: Solving Quadratic Equations by Factoring

Lesson 3: Solving Quadratic Equations by Completing the Square

Lesson 4: Solving Quadratic Equations by Using the Quadratic

Formula

2. Module 2: Nature of Roots and Problems Involving Quadratic Equations

Lesson 1: Nature of Roots of Quadratic Equations

Lesson 2: Sum and Product of Roots of Quadratic Equations

Lesson 3: Equations Transformable into Quadratic Equations

Lesson 4: Solving Problems Involving Quadratic Equations

3. Module 3: Quadratic Inequalities

4. Module 4. Quadratic Functions

Lesson 1: Introduction to Quadratic Functions

Lesson 2: Graphs of Quadratic Functions

Lesson 3: Finding the Equation of Quadratic Function

Lesson 4: Applications of Quadratic Function

Implementation of the Instructional Materials. Pilot testing was conducted in four schools for the implementation of the modules. The implementation stage involved the consistent design and product evaluation and meticulous monitoring – redesigning, updating, and editing – to enhance the product and ensure product delivery. Pilot testing was conducted in four different schools.

In the pilot testing of the modules, results revealed that the majority of the students found the modules fun and easy to understand. One of the students said, "It started the process in a brief and organized manner. The formulas and the steps are given or are stated in a way that is easy for us to understand". Another student said, "Yes because some activities are performed by a group so we can discuss and the teacher explained everything".

Students found the activities challenging. The time limit given to the students in each activity was challenging. This was reflected in their answers. One of the students said, "I find the activities challenging especially in the problem-solving. It takes time to solve it". Another student said, "Yes, because of the time limit". Students also found the modules enhanced their decision-making and problem-solving activity. The way by which the module enhanced students' decision-making and problem-solving activity is "By analyzing the problems that are difficult and making a decision for the process, solving and final answer" as said one of the students. Another student said, "In mathematical solving, it was able to enhance my problem solving such as understanding math problems, gathering data on graphs, and solving equations". The majority of the students found that the modules pushed them to think critically. One of the six dimensions of critical thinking is the analysis which was reflected in the students' answers. One student said, "Because you have to analyze the question first and understand fully before you answer". Another student said, "We think critically for us to solve the expressions and equations properly".

Evaluation of the Instructional Materials. Twenty (20) secondary teachers teaching Grade 9 evaluated the modules, after giving them the guides for the six cores of critical thinking skills and dimensions of problem-solving skills. The primary purpose of the evaluation was for the teachers to rate the quality of the modules to enhance students' critical thinking and problem-solving skills. A questionnaire checklist was provided to the teachers for them to rate each core of critical thinking skills and each dimension of problem-solving skills.

Evaluation of the Quality of the Modules for Critical Thinking Skills

The summary of the results revealed that the quality of the module to enhance students' critical thinking skills was "very good" for Modules 1, 2, 3, and 4 with the means and standard deviations of M=4.02, SD=0.63; M=4.04, SD=0.51; M=4.15, SD=0.51; M=3.95, SD=0.66, respectively. This shows that the teachers found the modules able to enhance students' six cores of critical thinking skills, namely: interpretation, analysis, inference, evaluation, explanation, and self-regulation.

Table 3. *Summary of the Results on the Quality of the Modules to Enhance Students' Critical Thinking Skills*

Module	*SD*	*M*	Interpretation
Module 1	0.63	4.02	Very Good
Module 2	0.51	4.04	Very Good
Module 3	0.51	4.15	Very Good
Module 4	0.66	3.95	Very Good

Note: Interpretation is based on the following scale. Quality of the Module: excellent (4.51-5.0), very good (3.51-4.50), good (2.51-3.50), fair (1.51-2.50), and poor (1.00-1.50).

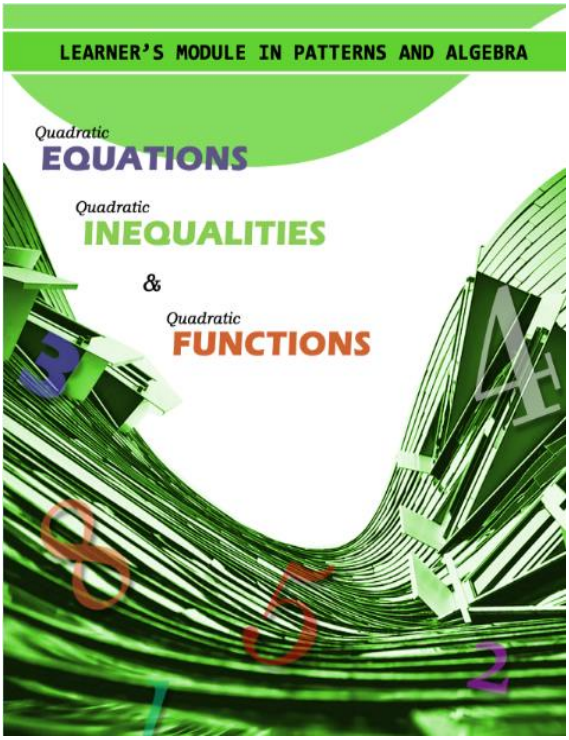
Summary of results on quality of the modules to enhance students' problem-solving skills. The summary of results revealed that the quality of the modules to enhance student's problem-solving skills was "very good" for Modules 1, 2, 3, and 4 with means and standard deviations of M=4.01, SD=0.63; M=4.14, SD=0.57; M=4.05, SD=0.50; M=3.94, SD=0.58, respectively. This shows that the teachers found the modules able to enhance students' four dimensions of problem-solving skills, namely: reading or extracting information from questions; sense-making or real-life and common-sense approach to solving problems; mathematical concepts,

mathematization, and reasoning; and standard and computational skills.

Table 4. *Summary of Results on Quality of the Modules to Enhance Students' Problem-solving Skills*

Module	*SD*	*M*	Interpretation
Module 1	0.63	4.01	Very Good
Module 2	0.57	4.14	Very Good
Module 3	0.50	4.05	Very Good
Module 4	0.58	3.94	Very Good

Note: Interpretation is based on the following scale. Quality of the Module: excellent (4.51-5.0), very good (3.51-4.50), good (2.51-3.50), fair (1.51-2.50), and poor (1.00-1.50).



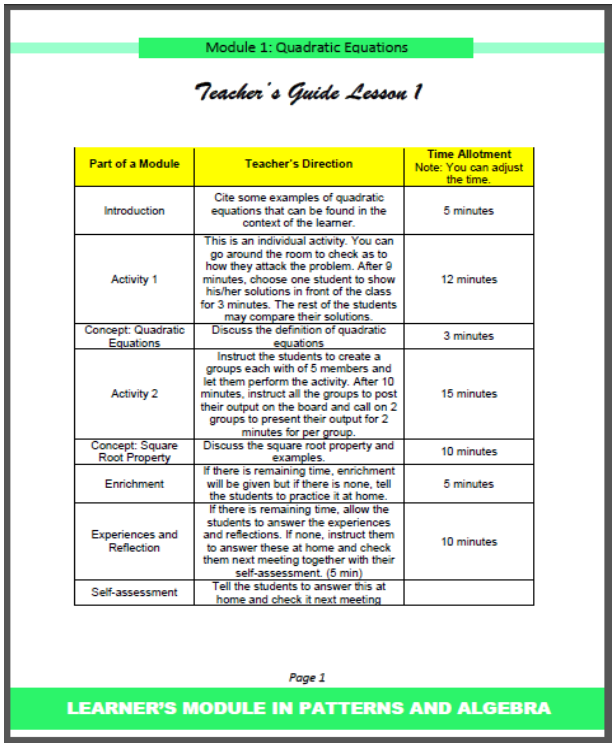


Figure 4. *Sample parts of the developed instructional materials*

Conclusions

In terms of critical thinking skills, students seem to have lacked the ability to analyze, evaluate, interpret, infer, explain and self-regulate. They appear to be biased in their interpretation of evidence, statements, graphics, questions, information, or other people's points of view; they fail to recognize or quickly dismiss strong, relevant counter-arguments; they ignore or superficially evaluate obvious alternative points of view; they argue with fallacious or irrelevant reasons and unwarranted claims; they do not justify or explain reasons, and they maintain or defend views based on no evidence or reasons.

Students appear to have insufficient knowledge and skills in reading or extracting information from questions, improving in sense-making or a real-life and common-sense approach to solving problems, performing and understanding mathematics concepts, mathematization, and reasoning, and accurately solving using standard and computational skills. These could be a result of their inability

to identify problems, build a coherent plan to solve problems, collect no useful information, and fail to solve problems.

It also appears that students have low levels of critical thinking and problem-solving skills in different content standards, specifically on quadratic equations, quadratic inequalities, and quadratic functions. One reason for this could be the insufficient instructional materials provided by the Department of Education. Moreover, the topics in these content standards are not properly and systematically arranged as attested to by the secondary mathematics teachers.

Recommendations

The following are the recommendations of the study:

1. The Department of Education (DepEd) needs to collate appropriate feedback and results in the implementation of the K-12 mathematics curriculum, revisit the curriculum guide for mathematics, and create a standardized assessment to gauge the critical thinking and problem-solving skills of students.

2. Both mathematics teachers and students need to visit the DepEd website and other learning resources for the improvement of mathematics learning.

3. Higher education institutions need to integrate module making or instructional material making in teacher education programs to train and develop prospective teachers in the formulation and development of learning activities and assessment of teaching-related activities.

4. Textbook writers have to look into the suitability of textbook content for all kinds of learners, the community, and the present situation. They may adopt parallel or similar activities and integrate problem-based learning strategies to enhance student's critical thinking and problem-solving skills.

5. Others researchers may conduct similar studies focusing on the subject areas, like geometry, trigonometry, statistics, and probability, and develop outputs for both teacher and student use.

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