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Design a module integrating problem based learning with fluid intelligence and evaluating its impact on the understanding of mechanical energy and machines

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Abstract

A module was designed and developed that integrates the steps of Problem-based learning (PBL) and fluid intelligence skills (PBL-FI Module), then evaluated its impact on the conceptual understanding (CU) of mechanical energy and machines (MEM) for 6th graders in Jordan. The module was developed using the ADDIE instructional design model, which included five stages: analysis, design, development, implementation, and evaluation. Ten experts verified reliability, content validity, and educational usability.

To evaluate the effect of the PBL-FI Module on conceptual understanding, as defined by Wiggins & Mctighe (2002), an inequivalent group quasi-experiment was designed and used, in which the sample was divided into two groups: experimental, which consisted of 47 students that were taught using the PBL-FI module; and the control group, which consists of 48 students that were taught using the traditional method. A pre-and post-test was applied to measure the understanding of MEM in each of the two study groups.

One-way ANCOVA analysis was performed to compare the two groups, and the results showed the superiority of the PBL-FI module compared to the traditional method in enhancing CU of MEM.

Introduction

Students need to understand the abstract concepts contained in the science curricula by building mental connections between these concepts (Algarni, 2016); According to John Dewey's constructivist theory, learning occurs through the construction of knowledge in the student's mind (Celik et al., 2011; Wewe, 2017), which can then aid students to link concepts to reach the optimal solution to the realistic problem given (Handayani, 2018). To ensure good understanding of

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concepts, Wiggins & Mctighe (2002) identified understanding in six areas: explanation, interpretation, application, perspective, empathy, and self-knowledge.

As a learning strategy based on constructivist theory, PBL introduces real life problems to the student. Therefore, the students are at risk of cognitive imbalance and confusion. To resolve this, small groups are needed with applying an organized steps to assist students reaching the cognitive balance that leads to solving this problem or explaining this ambiguous or confusing situation (Jaradat, 2013; Zeitoun, 2007).

Theoretical framework

Although educators have different views on the steps or stages of PBL, most agree on the following basic steps (Akacay, 2009; Jones, 2006; Shishigu, 2018; Nilson, 2014; Docktor, 2009; Delisle, 2001; Torp and Stage, 2002):

1- Preparing students to learn according to the PBL method.

2- Presenting the problem to be solved or the confusing (ambiguous) situation to be explained.

3 - Students understand the problem by defining its dimensions.

4- Students plan the solution through: collecting information, organizing ideas, using diagrams, conducting experiments, writing mathematical equations, necessary laws, and so on.

5- Offer some possible solutions to the problem.

6- Agreeing on the optimal solution to the problem within one group.

7- Checking the solution, by consulting with the rest of the groups, and consulting the teacher.

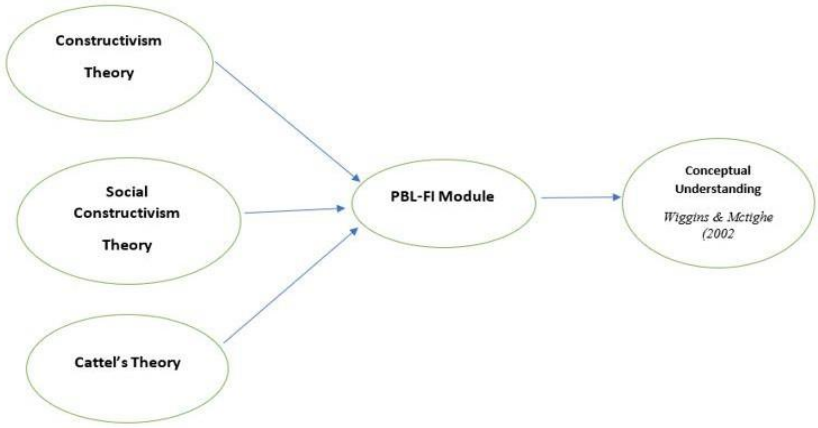
PBL is an inquiry strategy where you start with a problem or situation (question) that needs to be resolved or explained (Abdul Hamid, 1999; Holly, 1996; Zarqani, 2017; Jaradat, 2012, Zeitoun, 2007; Fidan & Tonsel, 2019).This new situation that in which the learner is confronted without prior knowledge that leads them to think independently and logically (in an attempt to attract their fluid intelligence (FI) skills); where fluid intelligence according to Cattell's theory is defined as the ability of the learner to solve new life problems without prior knowledge, and these skills are represented in analyzing variables, linking them, eliciting the relationship between them, and identifying patterns (Quasha, 2000; Sanginabadi, 2012) and this thinking may be cooperative among group members according to social theory (Wheatley, 1991 & Schunk, 2007), depending on the differences between them such as the level of FI (Al-Khalili et al., 1996).

PBL is a student-centered teaching strategy (Zerkani, 2017; Attia, 2015). The role of the learner is represented according to this strategy in three basic roles (Phillips, 1995): The first role is the active learner who discusses, inquiries and discovers concepts, the second role is the social learner who builds his knowledge through dialogue and sharing with peers is what Volatsky's called social construction. The final role is the creative learner who builds knowledge and arrives at new products by practicing higher-order thinking skills. While the role of the teacher is limited to facilitation and guidance only (Al-Jawadeh, 2006; Hussain & Jergeas, 2021).

So, problems drive the learning process, in partnership with a small working group that creates a learning environment in which teachers train students' thinking and direct students' inquiries to reach deeper levels of conceptual understanding (Trope and Stig, 2002; Zeytoun, 2007; El-Tounsi; 2013). Figure 1 shows the theoretical framework of PBL- FI Module design and its impact on CU.

PBL-FI module in MEM was designed and developed according to the ADDIE instructional design in its five stages: analysis, design, development, implementation, and evaluation (Widyastuti, 2019; Cheung, 2016; Branch, 2009; Peterson, 2003; Idoga & Kazaure, 2022; Muho & Taraj, 2022; Puruwita et al., 2022). Chosen for instructional unit design because it is distinguished from other paradigms of instructional design in terms of its ease of use and can be applied to approaches that examine knowledge, skills, or attitudes (Cheung, 2016; Peterson, 2003), ADDIE is also applied to construct performance-based learning, thus focusing on The student as the focus of learning and not the teacher (Branch, 2009), which is in line with the PBL strategy developed by the current study.

Figure 1 Theoretical Framework



Literature Review

In terms of research on PBL Modules, Handyani (2018) conducted a study that demonstrated the effectiveness of the developed PBL module in improving independent learning of Negeri students Yogyakarta, which increased learning outcomes for students who studied through PBL compared to the traditional method.

As for physics subjects, Serena's (2018) study proved that the development of an electronic unit based on PBL in heat and temperature positively affects the acquisition of eleventh grade students of scientific skills, and the ability to measure them. The electronic module was designed based on ADDIE, and its validity and reliability were verified by presenting it to a number of experts in the educational material and media aspects.

Sari, Ellizar, and Azhar (2019) also carried out another study in physics to investigate the effectiveness of developing a PBL module in electrolyte and non-electrolyte solutions in improving critical thinking skills. This developed module has obtained a high level of validity and practical application, which enables students and teachers to use it easily in the learning process, which increases students' ability to discover the concept and think critically (Alsahlawi, 2021; Mazur, 2021).

In terms of integration between the steps of PBL and other skills, Siew and Chin (2018) conducted a research aimed at designing and developing a module integrating PBL with cooperative learning using ADDIE, and then evaluating its effects on the scientific creativity of preschool children. The reliability and validity of the content was verified by being presented to five subject matter experts, pedagogical usability by being presented to 10 preschool teachers, and acceptability by preschool students by being applied to a survey sample of 30 preschool children. After that, it was applied to a randomly selected sample of 144 students at the age of six, and it proved effective in developing scientific creativity among pre-school students.

In the field of developing creative thinking, a study was conducted by Anjarwati, Sajidan, and Prayitno (2018) to test the effectiveness of a PBL unit that was developed around the topic of environmental changes in enhancing creative thinking skills of students. It was applied semi-experimentally to tenth grade students. It was found that the mean scores of the creative thinking skills of the experimental group that were taught using the developed PBL module was higher than the mean scores of the creative thinking skills of the control group that was taught in the usual way.

By browsing the previous studies of modules developed based on PBL, he found the effective effect of them on the various fields of learning, but the researcher did not find any educational module that integrates learning based on problem solving and fluid intelligence and evaluates its impact on conceptual understanding in the subject of mechanical energy and machines among sixth grade students in Jordan.

Questions of the research

There are two research questions guiding this study:

1. How to design and develop a module of problem-based learning and fluid intelligence (PBL-FI module) on the topic of mechanical energy and machines for the sixth grade?

2. Do students' scores differ on the conceptual understanding post-test according to the difference in the teaching method (PBL-FI Module/ Traditional Method)?

Research Design:

A quasi-experimental factorial design was used. Where four public schools containing the sixth grade were randomly selected in Irbid Governorate in Jordan during the second semester of the academic year 2021-2022. They were randomly divided into two groups according to the teaching method: the experimental group that was exposed to the PBL-FI module, numbering 47 students, and the control group that was exposed to traditional method (TM), numbering 48 students. A pre-test was applied to assess CU of MEM, and the same test was applied after completing the teaching of the two groups.

To design the module on the subject of MEM, the steps of PBL were combined with the skills of fluid intelligence, through the use of the ADDIE educational design model with its five stages (analysis, design, development, implementation, and evaluation), which are described as follows:

- Analysis stage

The purpose of this stage is to analyze the needs and analyze the leaners and context as follows:

a- Needs Analysis: The most important needs related to conducting the research were identified by organizing interviews with the 6th grade teachers in the study community, and asking them some questions regarding the research variables, as shown in Table 1.

b - Analysis the characteristics of the learner and the context: The characteristics of the 6th grade students were analysed in terms of first: The age of the students, as their ages ranged between (10-12) years. Second: Levels of FI, as the students in the study sample were classified according to their FI, by conducting a FI test, which is the standard Raven matrix, and based on the test results, they were be classified into 3 levels (high, medium, low). Third: Academic difficulties. After examining the students' previous grades in science and conducting interviews with some classes from a sample of schools and the teachers responsible for teaching these students, some students found it difficult to learn physics topics in general, and in particular to understand the concepts of MEM and their practical and mathematical applications.

Table 1: Teacher interview questions and responses for needs analysis.

Question	*Response*
What are the methods and strategies that you use in teaching mechanical energy and machines?	*The most used method is the traditional method that depends on the teacher's explanation. It may include questions for the student, but in an unorganized manner and without gradation in levels. Without giving enough opportunity for students to participate in finding solutions to problems or explaining situations. Cooperative learning is rarely used without clear, structured instructions and standards for groups. The focus is not on practical performance with specific goals and*

	scientific methodology. Computer and Internet technologies are rarely used to facilitate tasks and seek solutions to problems.
What do you know about conceptual understanding, and what are its areas?	*Most science teachers define CU as the acquisition of scientific concepts. They know 3 of its fields, which are explanation and interpretation without distinguishing between them, and its application.*
Have you carried out activities that contribute to the development of understanding of sixth graders in science subjects, including mechanical energy and machines? How do you do that?	*Some activities are used to increase CU, but most are teacher dependent. Without real interaction between students with each other, and with the teacher. Most of the activities focus on direct questions.*
How familiar are you with fluid intelligence skills?	*Most science teachers believe that the skills of FI are related to the ability and speed of the student to deal with the situations that confront him (Promptitude). They link intelligence to solving difficult and new questions. They believe that analysis and linking concepts are the most important skills of FI.*
How do you include FI skills in the activities offered to students in science classes?	*These skills are usually included as requirements for solving additional questions, and as an assignment.* *Usually, most students are not involved in activities that require fluid intelligence skills, so they are reserved for distinguished students.*
Do you conduct a test of FI for your students before starting to teach the curriculum, so that you can take into account their individual differences, and then benefit from that when using certain teaching strategies, or when presenting activities?	*Teachers never take a test that measures students' fluid intelligence, but a few of them may suffice with conducting a diagnostic test in the curriculum (which depends entirely on minimum skills). Therefore, the classification of students' levels may be unfair.*

Do you believe in the importance of developing a unit that enhances understanding of mechanical energy and machines based on a student-centered teaching strategy, integrating fluid intelligence skills with it?	*More than 95% of science teachers interviewed emphasized the need to build a module on mechanical energy and machines to overcome difficulty in understanding it, and it is essential that this module be student-based and include activities that consider Fluid Intelligence skills.*

Regarding the needs of the context, the administrative permits necessary to carry out the research have been taken from the Ministry of Education. It has also been confirmed that facilities such as laboratories, computers, the Internet, equipment and tools are available for students to perform lessons in cooperative groups. The resources necessary to develop the content of the module, which include scientific references and websites, a science book and a teacher's guide for the sixth grade, were also identified, and finally, educational concepts were defined.

- Design Stage:

The design phase consists of 3 basic procedures, which are the formulation of the objectives of MEM chapter, the planning of assessment tools, and finally the planning of the teaching method, as described in detail below:

a- Objectives of the chapter: 14 behavioural objectives were formulated from the mechanical energy and machines chapter based on the sixth-grade science book (Table 2).

Table 2: Learning objectives in mechanical energy and machines Chapter.

Objectives of the MEM chapter
1- To deduce the relationship between the distance traveled by the body and the energy it possesses. *2 - To deduce the relationship between the concept of work and each of force and displacement.* *3- To deduce the relationship between work and kinetic energy.* *4- To distinguish the forms of mechanical energy possessed by the body in different situations.* *5- To describe the transformations of mechanical energy in bodies in several life applications.* *6- To indicate the factors on which the gravitational potential energy depends.* *7- To devise the factors upon which the elastic potential energy is based.*

8- To design a practical method to increase the distance moved by a body below the inclined plane. *9- To deduce the factors on which kinetic energy depends.* *10- To derive the law of conservation of mechanical energy.* *11 - To calculate the mechanical energy of a body falling from a certain height at any point in its fall path.* *12 - Show how the following simple machines work: lever, inclined plane, pulley, wheel and axle, gears.* *13 - Calculate the force required to lift an object upward using the inclined plane.* *14 - Explain the inefficiency of machines by 100%.*

b- Constructing the assessment tool: A CU test was prepared to measure the impact of the PBL-FI Module, consisting of 32 multiple-choice items about MEM. Its validity and reliability have been verified.

c- Planning the teaching method: it's planned for each class so that the problems and ways to solve them are based on the steps of PBL and the skills of FI. The detail is as follows:

The lesson plan was designed according to the PBL-FI module as in Table 4, so that students are confronted with a new (real) problem that needs to be solved, through students practicing activities that require a different amount of FI skills. This includes the last stage in this design, evaluation and expansion, which contains questions consistent with 4 domains of understanding (explanation, interpretation, application, taking perspective) according to the model of Wiggins & Mctighe (2002), which were included in the test that was prepared to measure understanding.

With regard to the subject of MEM, the scientific problems were formulated in accordance with the educational objectives related to the subject of mechanical energy and machines, as indicated in Table 3. Regarding the fluid intelligence skills included in the activities, they may include pattern analysis, bending and paper cutting, understanding complex relationships between variables in new situations, classification and comparison , arrays and strings, and problem solving (Quasha 2000). While completing mathematical problems, they may include puzzles and any creative skills (Feeney, 2019).

Table 3: problems of MEM chapter.

1- Can you predict where a projectile you fire from a toy gun will land? How is that?
2- How do you explain the relationship of work to force and displacement (puzzle: the cards)

3- How is kinetic energy transferred to a stationary body? What is causing the movement of the car you see in the picture?
4- How does mechanical energy transform from one form to another in the bodies around us?
5- Khaled dropped 3 identical blocks from different heights, which sink deeper into the sandy floor?
6- How to increase the effect of the spring on the objects attached to it?
7- The traffic department sets different speeds for vehicles on the roads, justify that.
8- You dropped a football student from the top of the school roof to the bottom, and it hit the ground. What are your expectations for potential energy, kinetic energy, and mechanical energy in each stage of its fall?
9 - Ali wanted to remove a large stone - blocking the road in front of the house - from the surface of the earth. How can this be done?
10 - You have a heavy barrel that you want to lift to the truck bed with less force, suggest a suitable method for that?
12- A worker wants to lift bags of cement from the bottom of the building to the top. Suggest a way to help him get the job done as quickly and smoothly as possible.
13- The bicycle moves easily and easily, explain that based on the movement of the gears?
14- Paste the cards in front of you in the designated spaces on the machine diagram, to show the efficiency of the machine.

- Development stage:

At this stage, lesson plans for the mechanical energy and machines chapter were prepared according to a developed strategy that integrates the steps of PBL and the skills of fluid intelligence. The PBL-FI module consists of 14 lessons (problems), each of which requires approximately 40 minutes (one period) to complete. Table 4 represents a sample lesson plan as per the PBL-FI Module.

Table 4: Lesson plan Design.

<table>
<tr><td colspan="3">Lesson's Title</td><td colspan="2">……………………………………</td></tr>
<tr><td colspan="3">Lesson's Objectives</td><td colspan="2">It refers to a problem that is required to solve.</td></tr>
<tr><td>PBL-Steps</td><td>Teacher's Role</td><td colspan="2">Students' role</td><td>FI Skills</td></tr>
<tr><td>…..</td><td>…………</td><td colspan="2">………………….</td><td>……………………………….</td></tr>
</table>

Evaluation and Expansion: Questions or Tasks on domains of CU in the topic of MEM.

- Implementation stage:

This stage aimed at applying the developed PBL-FI module to sixth grade students, and then assessment its impact on developing understanding of MEM. Therefore, the researcher first obtained permission from the Directorate of Education to conduct the study, and after that he selected 2 schools at random, and took permission from the school principal to carry out the study after explaining the purposes of the research to him. After that, the researcher met with the targeted teachers and asked for their approval to carry out the prepared plan, then explained to them the implementation mechanism in detail. After that, the concerned teachers were provided with the necessary tools and materials, and all difficulties were overcome, and feedback was provided continuously. This implementation phase took 5 weeks.

- Evaluation stage

At this stage, the educational tools (teacher's guide according to Module PBL-FI, CU test, FI test) were validated. By submitting it to a committee of 10 experts representing university professors in teaching science, and teachers studying science and physics. They were asked to judge these tools from the following aspects: their suitability for the required objectives, the quality of language, wording and output, consistency and integration, taking into account the educational and technical aspects. Then the researcher received comments from all the experts and was committed to implementing their observations and suggestions that they agreed upon. In light of that, some necessary modifications were made to the initial version of those tools. Lessons were subsequently presented to a pilot sample of 27 students to see if there were problems faced by teachers and students when implementing the program.

Results and discussion:

To analyze the results of the research, one-way ANCOVA was used to compare the experimental and control groups, as Tables 5,6 show that there are significant differences in the mean of the CU post-test in favor of the students of the experimental group who were taught through the PBL-FI Module compared to the control students who were taught through CTM , after the pretest control. In other words, the PBL-FI Module succeeded in increasing the CU of the MEM.

This may be because the problems students encounter in the PBL-FI module are used as a means of deepening students' learning of concepts through their application rather than a direct presentation of facts and concepts (Duch et al, 2001). Where it presents students with real and meaningful situations that stimulate their thinking and they practice organized steps that lead to reaching the optimal solution to these problems, which enhances the understanding of scientific concepts (Pratiwi et al 2019).

The PBL-FI Module, which was designed in this study, is based on the learner as the focus of the educational process, so he plays an active role in discussing, investigating and discovering concepts, which increases his understanding of the concepts (Phillips, 1995). The PBL strategy, which in general focuses on students' self-learning, stimulates their conceptual understanding (Hussain et al., 2016).

Moreover, the lesson plans designed according to the PBL-FI Module for the chapter MEM contain questions in the evaluation and expansion phase that simulate the four conceptual understanding modes (explanation, interpretation, application and perspective taking), which may reflect positively on students' results in the CU test.

The results of this research are consistent with the positive effect of Modules PBL in enhancing learning in its various manifestations, as in studies: (Sari, Ellizar, Azhar2019; Serevina, 2018; Handyani, 2018; Kunwar et al., 2022; James & Andrew, 2022). However, the current study is unique in that it combined PBL with fluid intelligence and demonstrated its positive effect on comprehension in mechanical energy and machines among sixth graders in Jordan compared to TM.

Table 5 Mean and Standard Deviation of CUT Scores for Experimental and Control Group

Tests	*Groups*	*Numbers*	*Means*	*standard deviation*
Pre-test	*Experimental*	*47*	*8.85*	*2.62*
	Control	*48*	*7.75*	*3.16*
Post-test	*Experimental*	*47*	*18.40*	*3.38*
	Control	*48*	*11.71*	*3.58*

Table 6. One-Way ANCOVA Comparison Test (PBL-FI Module, CTM) Based on Post-test of CU

Item	*Sum of Squares*	*Degree of freedoms*	*Mean Squares*	*F*	*Significant*	*η^2*
Corrected Model	*1148.421*	*2*	*574.21*	*51.265*	*0.000*	*0.524*
Intercept	*1531.32*	*1*	*1531.32*	*136.342*	*0.000*	*0.594*
Group	*907.463*	*1*	*907.463*	*81.423*	*0.000*	*0.465*
Pretest	*59.53*	*1*	*59.53*	*7.92*	*0.000*	*0.079*
Error	*1041.2*	*185*	*5.122*			
Total	*23033.00*	*188*				

Corrected Total	*2195.868*	*187*				

PBL method designed by the researcher depends on the learner as the focus of the educational process, whose role is to discuss, investigate and discover concepts, which increases his conceptual understanding, making learning through learning one of the most important concepts (Philips, 1995). Teaching strategies focus on students' self-learning, stimulating their CU (Hussain et al., 2016).

In addition, PBL-FI module-designed lesson plans for the subject of MEM include questions in the assessment and expansion phase that simulate the four CU styles (clarification, interpretation, application, and perspective taking), which are included in the CU test for both control and experimental groups.

Regarding PBL Modules, which reached similar results to this study: (Sari, Ellizar, and Azhar, 2019; Serevina, 2018; Handyani, 2018), the current study is unique in that it combined PBL with fluid intelligence and proved its positive impact on the CU of MEM among Sixth-grade students in Jordan compared to TM.

Based on the above findings about the importance of developing integration modules between PBL and FI skills, the study recommends the necessity of circulating and applying this developed module by sixth grade science teachers because of its impact on the development of understanding in science subjects.

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