# The Effectiveness of PBL Online on Physics Students' Creativity and Critical Thinking: A Case Study at Universiti Malaysia Sabah

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Sponsor: I would like to thank the *Fundamental Research of Grant Scheme*, FRGS (Code FRG0016-SS-1/2006) fully sponsored by the Ministry of Higher Learning of Malaysia to make this research was a possible one.

## ABSTRACT

This paper aims at finding out the effectiveness of PBL Online on physics students' creativity and critical thinking. A cohort of 61 physics students from the School of Science and Technology (SST) of Universiti Malaysia Sabah, Malaysia comprised the sample. The sample was separated into experimental and control groups, with the experimental group was experiencing PBL online learning activities and the control group more to traditional learning activities. Both groups were supported via an online learning environment, which acted as the main medium for learning. Participants' creativity was evaluated using a previously validated instrument, the Torrance Test of Creativity Thinking (TTCT), whilst their critical thinking was using the Watson Glaser Critical Thinking Appraisal (WGCTA). Both tests administered before (pre-test) and after (post-test) the intervention. Examination of these data, points to statistically significant differences in both creativity and critical thinking favour to PBL group. Therefore the research findings suggest that PBL online effectively improves both of physics students' creativity and critical thinking.

***Keywords*:** problem-based learning; physics students;online learning; creativity; critical thinking.

# 1 Introduction

Unlike the past graduation from university is no guarantee of employment. This is particularly so in the case of Malaysia, the focus of this inquiry. The fact that ca. 70 percent of the graduates from public universities in Malaysia cannot secure employment is a cause of considerable anxiety. This paper seeks to address concerns expressed about higher education in Malaysia. In 2006, for example, almost 70 percent of Malaysian graduates were unable to secure employment (Ram, 2006), and in the Budget speech by the Prime Minister, the number of unemployed graduates in 2007 was reported to number about 31,000 (Shakir, 2009). The latest report revealed about 32,000 graduate students failed to get any job in any sector (Utusan Malaysia, 2010), something attributed to a lack of creativity, critical thinking and problem-solving skills. Hence, this paper seeks to develop a teaching and learning approach based on problem-based learning (PBL) to help Malaysian higher education teachers develop boths skills (i.e., creativity and critical thinking skills) in their students. The findings of this study are intended to provide science educators generally, and physics educators particularly, with fresh ideas for teaching and learning in undergraduate science courses that might inform the educational practice for physics graduates and go some way towards contributing to future proofing the physics workforce in times of rapid movement in technology and scientific knowledge. This paper also may help educators and researcher in higher education to better utilise online learning as an instructional tool. The intent here is not to generalise to all online learning courses, but to examine this one case in depth in order to understand the possibilities of integrating problem-based learning principles with online learning. This study thus may contribute to existing literature on online learning courses, and potentially impact on the practice of online learning

## 1.2 Creative Thinking and Learning Science

‘In the Malaysian compulsory education system, education about thinking emphasizes skills such as analysis, teaching students how to understand claims, teaching them how to follow or create a logical argument, how to figure out the answer, eliminate incorrect ideas, and focus on the ‘correct’ answer. This is a very traditional approach to learning science, one that suggest to students that science is a codified body of factual knowledge; a body of content that must be learned and repeated verbatim upon request (Millar, 1989). Harris (1998), however, suggests there is another kind of thinking we should foster; one that focuses on exploring ideas, generating possibilities, and looking for many right answers rather than seeking the one ‘correct’ answer. We suggest here that both ways of thinking are useful in working life after graduation, yet it seems the latter tends to be ignored until after college in many countries including Malaysia. According to Chua (2004), there are four main steps that we need to take in order to foster creative thinking: remove barriers to creative thinking; make students aware of the nature of the creative process; introduce and practice creative thinking strategies; and foster a creative environment.

In Malaysia, efforts are now being made to encourage creativity through both curricular and co-curricular activities ( Utusan Malaysia, 2008; L. S. M. Yong, 1986; 1993). As noted recently by the Deputy Prime Minister of Malaysia, Tan Sri Muhyiddin Yassin (also the Minister of Education), Malaysian education urgently needs to be transformed if we are to enhance economic development by application of creativity and innovation (Zakaria, 2010). Thus, in Malaysia teachers are encouraged to use pedagogies to promote creativity, and students are likewise encouraged to be innovative and come up with new ideas. Students are encouraged to participate in creative activities, allowing them to become conscious of the ways in which they think and learn.

## 1.3 Fostering Creative Thinking

Creativity or creativeness is a mental process or mental activity involving the generation of new concepts or theories, or new associations between existing concepts or theory (Cowley, 2005; Harris, 1998). An everyday conceptialization of creativity is that it is simply the act of creating something new (Awang & Ramly, 2008). However, according to Torrance (1984), creativity comprises four elements; *fluency*, *flexibility*, *originality*, and *elaboration*. Guilford (1964) says creativity involves 'divergent thinking', engaging in a process of creating many new and different thoughts about a topic over a short period of time.

## 1.4 Measuring Creative Thinking

It is not obvious how one could measure such an holistic construct like creativity. Based on the literature, it seems creativity is usually measured by means of survey instruments. The main instrument reported in the literature used to measure creative thinking is *Torrance Test of Creative Thinking* (TTCT, Forms A & B) (E. P. Torrance, 1990). Torrance (1966; 1990) suggests that creative thinking means to generate new ideas, the student must produce more and more ideas (i.e., be fluent), and include a variety of different ideas (i.e., be flexible), ideas that are unique (i.e., original ideas), and that such ideas need to be specific, detailed and useful (i.e., they are valuable). To measure these skills, the TTCT in Form A (for pre-test) and Form B (for post-test) are used. There are no major differences between the tests since the questions in each form revolve around six activities:

Flow-chart 1 *The creative thinking activities that implemented in this study.*

<u>Activity 1: Asking</u> - students need to ask as many questions as possible about the activities seen in a picture that is provided;

↓

<u>Activity 2: Guessing the causes</u> - students need to guess as many causes as possible, about what caused the event/occurrence shown in a picture that is provided;

↓

<u>Activity 3: Guessing the cause of an occurrence or an event</u> – students need to list as many causes as possible, for the causes or outcomes of what will happen because of the event/occurrence shown in a picture that is provided;

↓

<u>Activity 4: Improving the product</u> – students need to list the best and most extraordinary ways we could change a given form of a product to produce a more interesting or useful form of the product;

↓

<u>Activity 5: Extraordinary uses</u> - students need to list as many possible functions or ways in which a product can be utilized in a picture that is provided;

↓

<u>Activity 6: Supposing</u> – students need to list other things that might happen through, or be caused by, an occurrence that has already happened/occurred.

Each answer in this instrument is scored using the following criteria (i) fluency, (ii) flexibility, (iii) originality, and (iv) elaboration. Juremi (2003) reported good construct and criterion validity, for both versions of the TTCT in the Malaysian context, suggesting they would likely to be suitable for use in the present inquiry (see below for validation of instruments). Additionally, work by Ghouse (1996), supports the construct validity of the TTCT for two cohorts of students, who were taught how to think creatively, compared with a group taught traditionally.

## 1.5 Critical Thinking

Critical thinking skills are considered important by many authors (Browne, Freeman, & Williamson, 2000; Huitt, 1998), and most authors argue that students must learn to become more thoughtful about what they learn in order to develop skills in problem-solving. The main purpose for developing critical thinking skills in students is to prepare them to succeed in the future, and thereby improve their quality of life. Many authors now feel that education must consist of more than an unreasoning accumulation of facts and skills, and to become active participants in a contemporary community requires in students a highly-developed critical awareness to cope with life issues (Huitt, 1998). Most advocates of thinking skills such as critical thinking and creativity highlight the relevance of such thinking skills for everyday living. The argument here is that critical thinking is the art of taking charge of one's own mind, in which case its value is plain: if we can take charge of our own minds, we can take charge of our own lives. Other authors argue that critical thinking is not an isolated goal unrelated to other important goals in education (Rusbult, 2006). Rather, it is a seminal goal which, done well, simultaneously facilitates a host of other learning outcomes. Rusbult suggests critical thinking is best visualized as a core of education. To illustrate with an example, as students learn to think more critically, they may become more adept at mathematical, historical and scientific thinking. Critical thinking is not normally presented as an intrinsic part of instruction and students are not often exposed to explicit instruction in such skills, with teachers tending to take it for granted that critical thinking is automatic by-product of their teaching. However, Rusbult (2006) argues that without critical thinking being systematically designed into instruction, learning is likely ephemeral, and superficial.

Philosophers also have considered the value of critical thinking with authors such as Paul reminding us that critical thinking is a process of thinking to a standard (Paul, 1990). Simply being involved in the process of critical thinking is not enough; it must done well and should guide the establishment of our beliefs and impact on our behaviour or action. Proficient and critical thinking as an important element of life success to the movement of information age is emphasized by Huitt (1995), who claims that critical thinking needs to be a key focus in schooling. Huitt argues that old standards of simply being able to score well on a standardized test of basic skills cannot be the sole means by which we judge the academic success or failure of our students. Given traditional conceptualizations of the purpose of the education, one might expect that evaluation would focus on higher level thinking such as critical thinking. However, evaluation of general education programs tends to be driven by instrumentation such as national tests, and exams. Research of students' critical thinking skills is rare (Facione, Giancarlo, Facione & Gainen, 1995), and there are few multi-institutional and longitudinal studies which include sufficient control of variables and appropriate comparison groups (Ewell, 1993; Pascarella & Terenzini, 1991). Empirical research on critical thinking skills is further inhibited by disagreement among theoreticians with regards to the definition of the construct (Ewell, 1993; Jones & Ratcliff, 1993; Kurfiss, 1988). However, recent evaluation of critical thinking skill development suggests that at the college level at least, improvements in critical thinking have occurred (Astin, 1993; Ewell, 1993; Facione, 1990). The next section considers what pedagogies have been helpful in improving critical thinking.

## 1.6 Pedagogies Reported To Enhance Students' Critical Thinking Skills

The literature suggests that higher order thinking skills among students are essential in problem solving, and that critical thinking is an important part of problem-solving (Juremi, 2003). In addition, through explicit teaching of critical thinking, students are exposed to concepts such as inference, deduction, interpretation, judging and argument, all of which encourage them to think critically. There are many teaching approaches reported to improve critical thinking: project-based online learning (Kurubacak, 2006); dialogic-learning

(Frijters, Dam, & Rijlaarsdam, 2008); immersion learning (Warren, Memory, & Bolinger, 2004); a collaborative faculty approach (William, Macdermid, & Wessel, 2003); problem-solving (Zohar, Weinberger, & Tamir, 1994); evidence-based practice (Profetto-McGrath, 2005); asynchronous discussions (Walker, 2005); problem-solving on the Internet using Web-based authoring tools (Neo & Neo, 2000). For example, Juremi (2003) reports that a PBL approach improved students' critical thinking by teaching them explicit critical thinking learning process skill (i.e., evaluate all the relevant information and knowledge to solve a particular issue; thus by this phase the application of critical thinking subset will occur, making an inference, making an assumption, deduction, interpretation and also evaluation of argument). Other research by Zohar et al. (1994) likewise suggests that activities that expose students to use of critical thinking skills such as discussion in class and in a small group, experimental analysis, data management and problem-solving, are capable of increasing their critical thinking skills.

## 2 PROBLEM-BASED LEARNING

Problem-based learning (PBL) is a pedagogical approach to science education that focuses on helping students develop self-directed learning skills (Barrows & Tamblyn, 1980; Boud & Felleti, 1991). PBL has its origins in the Medical School of McMaster University (Rideout & Carpio, 2001), but has since been used in a varirety of other contexts. It derives from the idea that learning is a process in which the learner actively constructs new knowledge on the basis of current knowledge. Unlike traditional teaching practices in higher education, where the emphasis is on the transmission of factual knowledge, PBL consists providing students with a set of problems that are carefully sequenced to ensure the students are taken through the curriculum in a measured fashion. The students encounter problem-solving situations in small groups guided by a tutor, who facilitates the learning process by asking questions and monitoring the problem-solving process. The ability to solve problems here is more than just accumulating knowledge and rules; it is the development of flexible, cognitive strategies that help analyse unanticipated, 'ill-structured' situations with an end result of producing meaningful solutions. Even though many of today's complex issues are within reach of student understanding, according to the literature the skills needed to tackle these problems are often missing in our pedagogical approaches (Hitchcock, 2000; Hmelo-Silver & Lin, 2000).

Research points to positive feedback from students engaged in PBL, with a number of self-reported benefits identified: having fun learning; learning from each other; not falling behind as everyone is constantly learning; more effective learning as PBL enables students to remember better; students having to interact; and, real-life problems seen as more interesting and challenging (Dublin Institute of Technology, 2005). However, PBL is not just about problem solving, and it is important to distinguish between PBL and learning *via* problem-solving. In physics, the use of learning problem-solving is well established, and in this students are first presented with content, in the form of a lecture, and are then given problems to solve which are typically 'solved' via the use of algorithms or comparison with worked examples. These 'problems' are typically narrow in focus, test a restricted set of learning outcomes, and usually do not assess other key skills. This type of drill work is not problem solving in the sense that scientists view problem solving; it is rather learning how to solve numerical problems. When learning in this way, students do not get the opportunity to evaluate their knowledge or understanding, to explore different approaches, or to link their learning with their own needs as learners. They have limited control over the pace or style of learning, and according to the literature this method tends to promote surface learning (Woods, 1994). Surface learners concentrate on rote memorisation (Araz & Sungur, 2007); this often arises from the use of didactic 'spoon-feeding', which does not encourage students to adopt a deep approach to learning (Kember, 2000; Kit Fong, O'Toole, & Keppell, 2007). Deep learners, in contrast, use their own terminology to attach meaning to new knowledge (Rideout &

Carpio, 2001). In PBL, students determine their learning issues, and develop their own unique approach to solving problems. The members of the group learn to structure their efforts and delegate tasks, and peer teaching and organisational skills are critical components of the process. Students learn to analyse their own and their group members' learning processes and, unlike problem-solving learning, must engage with the complexity and ambiguities of real life problems. PBL is thus well suited to the development of key skills, such as the ability to work in a group, problem-solving, critiquing, improving personal learning, self-directed learning, and communication.

Despite these potential advantages, there is some reluctance about using PBL in physics because of view that students require a sound body of content and good mathematics skills before they can engage with this type of approach (McDermott & Redish, 1999). It has been reported that first year students tend to rely more on lecture notes than students in later years, and that first year students tend to be assessment driven (Dublin Institute of Technology, 2005). However, it also has been reported that PBL can be introduced successfully into first year, if it is facilitated correctly and the tutors are aware that the students are only in the early stages of developing as self-directed learners (Dublin Institute of Technology, 2005).

PBL appears, to at least in part, address concerns about other educational methods noted in the literature, such as how to enhance creative and critical thinking (Ward & Lee, 2002). According to Meier, Hovde, and Meier (1996), students taught within a teacher-dominated, lecture-based system are not able to solve problems that require them to make connections and use relationships between concepts and content. Only emerging scientists who are trained and taught to think creatively are likely to be able to solve real life problems. The literature thus suggests if we want our future scientists to be capable of solving some of the problems facing society, then we need to find ways to develop creative thinking skills in our students.

The research reported in this inquiry seeks to investigate the effectiveness of PBL in enhancing students' creativity skills in Malaysia, and at to see whether or not there is any positive impact on students' critical thinking.

## 2.1 PBL online

There is now a substantial literature on how PBL and online learning can be combined (2009see, e.g., Candela et al., 2009; Cheaney & Ingebritsen, 2005; Jennings, 2006; Lee, 2006; Lim, 2005), a combination that is often called *PBL online*. The argument in favour of this combination is that PBL online is capable of promoting both the development of problem-solving, and students' ability to use information technology; emphasizing the advantages of PBL as a promoter of process, as opposed to content (Watson, 2002). At first, technology was only used by teachers for administrative purposes, or for information dissemination (Lim, 2005), but as teachers became more familiar with such technologies, they sought to explore the potential of ICT in delivering collaborative inquiry through online forums (Lim, 2005). Some authors report integrating constructivist-based education of practical work such as PBL with online learning (Lim, 2005).

Integrating PBL with online learning consists of merging the pedagogy (in this case PBL) and delivering the content partly, or entirely, online via the Web. A key feature of PBL online is the online collaboration that occurs as part of the learning activities (M. Savin-Baden & Wilkie, 2006), and this focuses on team-oriented knowledge-building discourse, and reduced teacher-centred learning (M. Savin-Baden, 2006). Savin-Baden also note that PBL online involves students working collaboratively in real time, or asynchronously, and collaboration tools such as shared whiteboards, video conferencing, group browsing, e-mail, and forum rooms are important for the effective use of PBL online. Students can learn through the use of Web-based materials such as text, simulations, videos, and demonstrations (M. Savin-Baden & Gibbon, 2006). In some cases, no print materials are provided, and students only can access materials directly from the course website (see e.g., Yong, Jen, & Liang, 2003). In other cases there is a focus on a particular website, through which students are guided by the use of strategy problems, online material and specific links to core material, rather than delivery of PBL solely online (e.g., Savin-Baden & Gibbon, 2006). In both cases, use of websites is mostly student led/driven, and the materials provided support the learning undertaken in face-to-face PBL groups. An example of such a site is that for the SONIC project (Student Online in Nursing Integrated Curricula) (M. Savin-Baden & Gibbon, 2006), which used PBL in an interactive environment using FlashPlayer-based physiology resources in order to improve students expertise in nursing. Savin-Baden and Gibbon in an investigation of the interrelationship of PBL and interactive media, report that the assessment of PBL combined with interactive media to date has not fully considered the difficulties of combining these two approaches.

It is reported that PBL online has many of the trademarks of traditional PBL models developed in 1960s at McMaster University, and delivered through face-to-face pedagogy. PBL online, like traditional PBL, is more than a linear approach to problem solving, where problem scenarios are used as key learning or key issues in online learning environments. However, Savin-Baden and Wilkie (2006) say that many practitioners, educators and researchers hold concerns about whether PBL online might adversely affect the existence of face-to-face PBL, because PBL online may be seen as being more cost effective. One concern here is practitioner anxiety that PBL online may conflict with intentions of PBL generally, since some forms of PBL online tend to put more emphasis on solving closely defined problems, meaning PBL online may be less successful in encouraging students to become independent inquirers. A second concern is that learning in groups online may inhibit students' capacity to work through team difficulties and conflicts in the way this occurs in face-to-face PBL (M. Savin-Baden & Wilkie, 2006). Nevertheless, PBL online is an approach that stresses complementing, constructing, and improving what is already in existence, rather than trying to replace face-to-face learning pedagogies (Gossman, Stewart, Jaspers, & Chapman, 2007; M. Savin-Baden & Wilkie, 2006), and it is reported that PBL online promotes good cognitive engagement among students (Gossman et al., 2007).

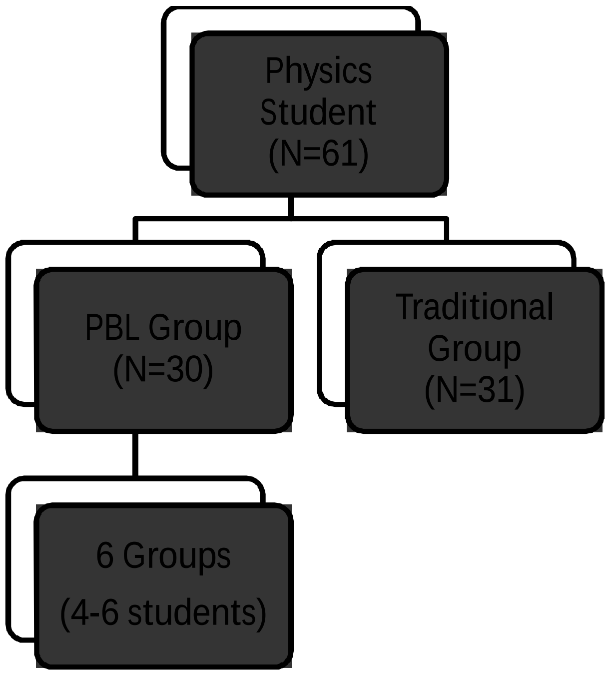
There is little in the literature about integrating PBL online and creative thinking in non-Western settings such as Malaysia. Thus, this study seeks to contribute to the literature by considering how we might foster creative thinking amongst science students and pre-service science teachers' using PBL online for physics.

## 3 METHODOLOGY

The study was conducted in Semester II during the 2008/2009 academic year at the University Malaysia Sabah (UMS), Malaysia. A cohort of 61 physics students from the Physics With Electronic Programme of School of Science and Technology (SST) were involved. The student separated into experimental and control groups. The experimental group pursued all the PBL learning activities (i.e., collaborative learning, independent learning, self-directed learning, and reflective learning), while the control group were taught in a traditional lecture based learning manner. Both groups were provided with an online learning environment (i.e., using the same learning management system - Moodle).

For the PBL group, the students were divided into 6 groups of 4-6 students. Whilst for the traditional group, there were no groups involved, and they studied individually (Flowchart 2).

Flowchart 2. *Sample used for the study*




The intervention was conducted over 16 weeks. The Torrance Test of Creative Thinking (TTCT) and the Watson Glaser of Critical Thinking Appraisal (WGCTA) instruments was administered one week before classes as a pre-test, and one week after the intervention as a post-test. During the intervention, all the teaching and learning assessment was delivered using the learning management system (LMS) organized by the Educational Technology and Multimedia Unit (ETMU) of the Universiti Malaysia Sabah. The LMS was developed in 2007, and the first author and lead researcher prepared the LMS following PBL and traditional approaches.

For the PBL groups the learning activities started with problems. After they were introduced to the problem, the students had to find their own sources of information in order to develop an appropriate solution. They could find solutions via the Internet, from interviews with their lectures or tutors, from textbooks, observations, or any method they felt would provide relevant information to help them solve their problems. The students in the PBL group also had to access to the LMS to engage in chat rooms at least once in a week – this was monitored by a facilitator. In these chat rooms they could argue, share thoughts, and start to construct solutions to the problems posed. They also could enter a forum room to post any inquiries or any ideas asynchronously. Additionally, some linkages, sources and lecture notes were uploaded by the facilitator to ensure the students did not lose their way when trying to find suitable solutions. They were given two weeks to solve each problem, and they had to solve five problems over the semester. In PBL online approach, students separated into 6 groups as it consist of 4-6 members. Before they started with the intervention they had been given with a series of daily life situation problems that related to the Modern Physics's syllabus. In the first week they distributed the task among group members. Before go on to their further research, they discussed about their hypothesis and prior knowledge about the issues either online or by conventional method. The following task is the individually independent research to find any related information, ideas, knowledge, or notes to support their explanations about the issue. The following weeks they meet up again via online to discuss, analyse and synthesize their information whether it will be the best solution. If not, they will do the same process in finding the information individually and will come up ones again in a group discussion through online and continue discussing on their matter. The process will continue until the group come up with the best solution for each daily live problem given.

For the traditional group, no major differences were made in terms of their learning activities compared with their usual face-to-face traditional teaching approach. The students in both cohorts were familiar with the LMS, where they already had experience in downloading and reading lecture notes online, accessing tutorial questions and assignments. They were required to submit all answers to tutorial problems and assignments via the LMS, but received no additional learning activities. This use of the LMS, Moodle 2007, followed the suggestion of Jayasundara et al. (2007) that PBL online is easier if it is incorporated into existing learning management systems such as Moodle and Blackboard.

In summary, in this inquiry the intention was to improve students' creativity and critical thinking via a PBL online intervention. For creativity, the data were collected through a creative thinking test - the TTCT, which as noted above contains four criteria used to evaluate creative thinking. There were two versions of the creative thinking test employed, a pre-test (Form A) and post-test (Form B). Whilst for critical thinking, the data were collected through a critical thinking test – The WGCTA. There were also two sets of critical thinking test (i.e., *pre*- and *post-test*). The purpose of conducting the pre-test was to make sure the students from the cohorts were comparable in term of their creativity and critical thinking, and the post-test are intended to see if there were any significant differences after the intervention. The tests were administered in Week 1 and Week 16 of the semester.

Content validity in this administration was checked by a lecturer in the area of creative and critical thinking (at another university form that where the survey administration occurred) who checked the instrument for suitability in evaluating both thinking skills, and an English language teacher checked the instrument for clarity of English language. The instruments for the present study also validated from a pilot study, where a group of students answered the questions and gave feedbacks. This resulted in minor linguistic modifications for clarity.

Creative thinking was evaluated using the four elements that form the basis of the instrument described above; viz., *fluency* (i.e., students give as many answer as they can), *flexibility* (i.e., students give as many themes of answers as they can), *originality* (i.e., students give authentic answers that are different from others), and *elaboration* (i.e., students give cause and effect for each answer). Whilst Critical thinking was evaluated using the five elements that form the basis of the WGCTA (i.e., *inference; assumption; deduction; evaluation argument; interpretation*).

## 4 RESEARCH FINDINGS

The performance of students from the SST program in the Torrance Test of Creative Thinking is provided in Table 1. These data suggest that the students who took part in the intervention performed about the same as the traditional group prior to the intervention. After the intervention, both groups performed better in a way that was statistically significant (PBL mean = 135.04, SD = 63.41; traditional mean = 110.23, SD = 47.88). PBL cohort performed better, where there were statistically significant differences between the groups when the instrument is considered overall for Mann-Whitney U test (z = -2.13, asymp. sig (2-tailed) = 0.03*<0.05) but not for Independent Sample t-Test analysis (sig. (2-tailed) t=-1.73, p = 0.89>0.05). However, since the data were not normally distributed, in this case the researcher accepted the data from the Mann-Whitney U test analyses. More detailed analysis of the instrument scales shows some interesting differences between the groups.

Table 1 shows there are statistically significant differences between the PBL and traditional groups in three scales, with the PBL group performing better for *flexibility*, *originality* and also *elaboration* (Mann-Whitney U test; z = -2.40, asymp. sig (2-tailed) = 0.02*<0.05; z = -2.81, asymp. sig (2-tailed) = 0.01*<0.05; z = -1.73, asymp. sig (2-tailed) = 0.04*<0.05 respectively). The same situation occurs when the data are analyzed with the Independent Sample t-Test where the PBL cohort produced better means in *flexibility*, *originality* and *elaboration* significantly (t=-2.22, p=0.03*<0.05; t=-3.06, p=0.00*<0.05; t=-2.44, p=0.02*<0.05 respectively). No significant difference noted for fluency criterion.

Table 1 *Report of Physics Students' mean marks for creative thinking pre- and post test by criterion*

| Creative Thinking Criterion | | Approach | | | | | |
|---|---|---|---|---|---|---|---|
| | | Traditional (N=31) | | PBL (N=30) | | | Difference in Post-Test |
| | | Pre-Test | Post-Test | Pre-Test | Post-Test | | |
| | | | | | Mann-Whitney U Test | Independent Sample t-Test | |
| **Fluency** | Mean | 27.93 | 50.32 | 22.96 | 50.39 | | -0.07 |
| | | | | | z=-0.56, Asymp.Sig =0.58 | t=-0.01, p=0.99 | |
| | *SD* | *13.61* | *24.29* | *15.95* | *20.36* | | *3.93* |
| **Flexibility** | Mean | 20.21 | 36.48 | 13.80 | 45.00* | | -8.5 |
| | | | | | z= -2.40, Asymp. Sig = 0.02* | t=-2.22, p=0.03* | |
| | *SD* | *9.50* | *12.08* | *7.89* | *17.48* | | *-5.4* |
| **Originality** | Mean | 3.62 | 14.05 | 4.72 | 24.44* | | -10.4 |
| | | | | | z = -2.81, Asymp. Sig = 0.01* | t=-3.06, p=0.00* | |
| | *SD* | *5.25* | *9.91* | *4.54* | *15.98* | | *-6.0* |
| **Elaboration** | Mean | 3.86 | 9.38 | 2.40 | 15.22* | | -5.8 |
| | | | | | z = -1.73, Asymp. Sig = 0.04* | t=-2.44, p=0.02* | |
| | *SD* | *3.25* | *5.54* | *2.95* | *12.09* | | *-6.6* |
| | | | | | | | |
| **Overall** | Mean | 55.62 | 110.23 | 43.88 | 135.04* | | -24.81 |
| | | | | | z = -2.13, Asymp. Sig = 0.03* | t = -1.73, p = 0.89 | |
| | *SD* | *27.73* | *47.88* | *28.05* | *63.41* | | *-15.53* |

*Note*: *****Statistically significant differences between PBL and traditional groups for post-test scores (independent sample t-test an Mann-Whitney U test)
This was an open-ended test, and so there are no maximum or minimum scores, as occurs with other closed-item instruments

The performance of students in the WGCTA is provided in Table 2. These data suggest that the students who took part in the intervention performed about the same as the traditional group prior to the intervention. After the intervention, both groups performed better (PBL mean = 45.64, SD = 5.99; traditional mean = 43.55, SD = 4.10), and although the PBL cohort performed a little better, there were no statistically significant differences between the groups when the instrument is considered overall by Independent Sample t-Test analyses (sig. 2 tailed, t=-1.59, p=0.12>0.05). However, when the data are analysed with the more sensitive Mann-Whitney U test, it appears the PBL group performs better than the traditional group (z=-2.16, asymp. sig (2 tailed) =0.03*<0.05). This is probably because of the relatively modest sample size (N=61), which when analysed with t-Test cannot be detected. Thus, the second analysis using Mann-Whitney U test shows a more useful outcome since it is more appropriate for the small non-parametric sample.

In addition, more detailed analysis of the instrument scales shows some interesting differences between the groups. There are statistically significant differences between the PBL and traditional groups for one scale, with the PBL group performing better for *inference* when measured via the independent sample t-test (t=-3.35, p=0.00*). As for the other scales, there were no statistically significant differences observed. However, when the data were once again analysed with the Mann-Whitney U test, the result indicates that for two out of five criterion the PBL group performed better than the traditionally taught counterparts (*inference*, z=-3.13, asymp. sig (2 tailed) = 0.00*<0.05; and *evaluation argument*, z=-2.38, asymp. sig (2 tailed) =0.02*<0.05 respectively). Nevertheless, the traditional group has a significantly higher mean in the *assumption* criterion (z=-2.30, asymp sig (2 tailed) = 0.02*<0.05) compared to PBL group. Again, this probably happens because of the small sample.

Table 2 *Report of Physics Students' mean marks for critical thinking pre- and post test by criterion*

| Critical Thinking Criterion | | Approach | | | | | |
|---|---|---|---|---|---|---|---|
| | | Traditional | | PBL | | | Difference in Post-Test |
| | | Pre-Test (N = 31) | Post-Test (N = 31) | Pre-Test (N = 30) | Post-Test (N = 30) | | |
| | | | | | Mann-Whitney U test | Independent Sample t-Test | |
| Inference | Mean (SD) | 4.24 (2.20) | 5.40 (1.62) | 3.77 | 7.18* | | -1.78 |
| | | | | | z =-3.13 Asymp. Sig = 0.00* | t =-3.53 p = 0.00* | |
| | *SD* | *2.20* | *1.62* | *2.84* | *2.46* | | *-0.84* |
| Assumption | Mean | 7.52 | 10.35 | 7.37 | 9.55* | | 0.80 |
| | | | | | z =-2.30 Asymp Sig = 0.02* | t = 1.77 p = 0.82 | |
| | *SD* | *3.42* | *1.32* | *4.22* | *2.15* | | *-0.83* |
| Deduction | Mean | 6.93 | 10.15 | 5.87 | 10.77 | | -0.62 |
| | | | | | z =-1.91 Asymp Sig = 0.06 | t = -1.57 p = 0.12 | |
| | *SD* | *3.37* | *1.47* | *3.97* | *1.64* | | *-0.17* |
| Interpretation | Mean | 7.10 | 9.30 | 5.53 | 9.14 | | 0.16 |
| | | | | | z =-1.08 Asymp Sig = 0.28 | t = 0.47 p = 0.64 | |
| | *SD* | *3.23* | *1.29* | *4.25* | *1.42* | | *-0.13* |
| Evaluation Argument | Mean | 6.55 | 8.35 | 5.20 | 9.00* | | -0.65 |
| | | | | | z = -2.38 Asymp Sig = 0.02* | t =-1.82 p = 0.74 | |
| | *SD* | *3.48* | *1.53* | *4.00* | *1.23* | | *0.30* |
| | | | | | | | |
| Overall | Mean | 32.00 | 43.55 | 27.37 | 45.64* | | -2.09 |
| | | | | | z =-2.16 Asymp Sig = 0.03* | t =-1.59 p = 0.12 | |
| | *SD* | *12.82* | *4.10* | *15.73* | *5.99* | | *-1.89* |

*Note*: *****Statistically significant differences between PBL and traditional groups for post-test scores (Independent Sample t-Test and Mann-Whitney U test)

Maximum mark is 80

# 5 DISCUSSION AND CONCLUSION

The research findings reported in this paper suggest that physics students' achievement in terms of creativity as measured by the Torrance Creative Thinking Test (TCTT) when engaged with PBL online scored better when compared with the traditional group. The overall sum showed there is a significant difference favour the PBL group. It seems that the PBL online students did better for the scales *flexibility*, *originality* and *elaboration*. These findings quite similar to work reported by Tan (2000) and Juremi (2003), who say that PBL online increases students' creative thinking.

As for the critical thinking, the *inference* criterion shows a difference in favour of the PBL group, in contrast to the *assumption* criterion, where the traditional group noted a higher difference. Upon further analysis, it is evident there is no significant difference in critical thinking when analysed using the Independent Sample t-Test. However, when the data are analysed using the Mann-Whitney U test, it appears that critical thinking for the PBL group for the SST cohort increased in contrast to the traditional group overall. Moreover, there are differences for the *inference* criterion (measured using both the Independent Sample t-Test and Mann-Whitney U test) and *evaluation argument* criterion (for the Mann-Whitney U test), with the PBL group performing better compared to their traditional counterparts. In the case of the *assumption* criterion, the traditional group scored higher compared with the PBL group. In summary, these findings suggest that, overall, students who engaged with the PBL method showed positive improvement in critical thinking compared to the students treated with traditional method.

The research findings suggest that the achievement of physics students improved their critical thinking for certain criteria (i.e., *inference* and *evaluation argument*). These findings are consistent with research findings reported by Zohar et al. (1994), who say that students exposed to PBL improved their critical thinking. Likewise, Juremi (2003) reports improved critical thinking for three criteria (i.e., *inference*, *interpretation* and *evaluation argument*) for a face-to-face PBL group. Kamin, O'Sullivan, Deterding, and Younger (2003) report that a PBL group employing virtual media were more engaged in critical thinking than a traditional cohort. This might be because the PBL students were exposed to explicit critical thinking learning process skills. In PBL, the *inference* element requires students to differentiate the falsity and truth of inference, based on data provided. Students decide whether or not the suggested inference is true, false or fake, or if not enough information is provided to reach a conclusion. Additionally, students have to *evaluate arguments* when dealing with problems. They have to differentiate between weak and strong arguments, and identify the best solution. Through PBL learning activities, these elements of critical thinking are explicated. Thus, students always practice these skills when using PBL. As a result, this learning method enables students to more easily answer the questions in the Watson Glaser Critical Thinking Test even though sometimes this involves outside knowledge, that is, other than subject content knowledge - in this case from a modern physics context. This may be due the nature of the science students learning experiences, in which they are nurtured in science thinking (such as science process skills) more deeply compared with pre-service teachers and engaging with learning activities that are consistent with this approach. In overall conclusion the research findings suggest that PBL online effectively improves both of physics students' creativity and critical thinking.

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