

Learning About Safety, Prevention and Quality of Life Through PBL: Implications for Teacher Education

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ABSTRACT

In Problem-Based Learning (PBL) students learn ‘new’ knowledge by solving problems. Studies focusing on the efficacy of PBL for the learning science content knowledge are rare and their results are not fully consistent. This study aims at: comparing the effectiveness of a transdisciplinary PBL and traditional teaching with regard to students’ learning of science knowledge within the scope of the theme Safety, Prevention and Quality of Life; finding out students’ opinions on transdisciplinary PBL approach. The sample is made of two 9th grade classes of a school located in the north of Portugal. The experimental class (24 students) approached the theme through PBL in an integrated way that is, Natural Sciences and Physical Sciences teachers pooled together the concepts that they were supposed to teach and organized PBL oriented teaching as if those concepts belonged to a single school subject. The control class (25 students) studied the same theme through traditional teaching, with the concepts of each school subject addressed separately by each one of the teachers. Data relative to content learning were collected by means of a pre- and a post-test and data relative to PBL students’ opinions on the new teaching approach were collected through an opinion questionnaire. Results indicate that transdisciplinary PBL led to a bit better results than traditional teaching and that students valued PBL.

CONTEXT OF THE RESEARCH

Problem-Based Learning (PBL) is a student-centred teaching approach that is consistent with the key principles of active learning as it is defined by Savery (2006) and Tan (2004). In a PBL learning environment, students are at the centre of the teaching and learning process (Barrows 1986; Barrows, 1996; Boud & Feletti, 1997; Lambros 2002; Hmelo-Silver, 2004) and they play an active role in it as they have to take the appropriate actions to learn (deeply) knowledge (that is new to them) by solving problems (Dahlgren, Castensson & Dahlgren, 1998).

In a PBL approach, problems are the starting point for learning (Barrows, 1986; Barrows, 1996; Dahlgren, Castensson & Dahlgren, 1998; Lambros, 2002; Hmelo-Silver, 2004). They determine what students learn, as this depends on the problem-solving process demands concerning knowledge and skills. Problems are qualitative or quantitative statements that offer an obstacle to problem-solvers who have to find strategies to overcome the obstacle and to reach a solution (Pozo, Postigo & Gómez-Crespo, 1995; Neto, 1998; Jonassen, 2004). To succeed in doing so, students need to use conceptual and procedural knowledge within the scope of the field(s) of the problem, as well as appropriate problem-solving strategies (Hmelo-Silver, 2004). Usually, problem-solvers do not possess all the necessary knowledge and skills and therefore they need to develop them (through study, inquiry, etc.) before being able to reach a good solution (if there is one for the problem that is at stake) or concluding that the problem has no solution.

In a PBL learning environment, teachers do not teach in the usual sense (Dahlgren, Castensson & Dahlgren, 1998; Chin & Chia, 2004). They are not there to *tell science* or to even to explain science concepts to students (Leite & Esteves, 2012). Thus, there is a risk that they feel that they are not playing their role as teachers (Li & Du, 2015). If it is the case, it may interfere negatively with the learning environment, as they may reduce

students' learning freedom and responsibility. This is why teachers may need support (Goodnough & Nolan, 2008; Pepper, 2009; Morgado, 2016) before they are used to and become comfortable with PBL.

However, as it was discussed in another paper (Leite & Esteves, 2012), in a PBL context, teachers have a variety of important roles to play and many key things to organize and monitor. Above all, teachers *are there* to stimulate students' curiosity through scenarios or problems that interest to students and that make them feel willing to engage into a problem-solving process (Lambros, 2002). In doing so, teachers provide students with learning opportunities that these may feel as being relevant for school as well as for daily life purposes. Nevertheless, within school systems that acknowledge curricula which are not problem-based (as defined by Boud and Felletti, 1997) students' learning possibilities are often conditioned by the problems that are selected by the teacher. As a matter of fact, when making this selection, the teacher bears in mind a mandatory curriculum that requires certain concepts, laws and theories to be taught and learned at a given school level.

Besides, teachers have other key roles to play, namely to guide students' work towards learning goals achievement and to ascertain that learning takes place (Dahlgren, Castensson & Dahlgren, 1998; Hmelo-Silver, 2004). In the former case, teachers need to prevent the possibility of having students stuck before some difficulty, as this would cause demotivation and even frustration along with waste of time. The idea is not that the teacher gives direct answers to students' questions but rather that he/she 'answers them' by asking other questions (Hmelo-Silver, 2004) that make students think about relevant issues or rethink some procedures, or redistribute the group roles, etc. In the latter case, teacher needs to ascertain that learning takes place. To do so, he/she needs to use appropriate tools both during the problem-solving process (e.g., questioning the problem-solving teams about their achievements and the foundations of their actions) and afterwards. In fact, by the end of the process, teacher should promote a new knowledge synthesis (Hmelo-Silver, 2004) or revision (if necessary) and a retrospective analysis of the problem-solving process. On one hand, asking students to make the synthesis themselves can make evident the need for knowledge revision through appropriate remediation strategies, which should be student-centred, consistently with the PBL underlying philosophy. On the other hand, the retrospective analysis can help students to develop an awareness of the problem-solving strategies that showed to be more or less useful, as well as the team members' actions and behaviours that were more or less productive and consistent with the group's mission.

Arguments for teaching science through a PBL approach (see, for example, Hmelo-Silver, 2004; Lambros, 2004; Azer 2008) assume that PBL may enable students to:

- learn science content knowledge, as problems focus on some science issue that is new or partly new for the students and that needs to be mastered before the problem solution is reached;
- learn procedural knowledge, including problem-solving skills and science process skill, as students need to find the most appropriate strategies to solving the problem. Reaching this goal may require the use of several process skills, some of which may be new to the students;
- develop interpersonal skills, as PBL is usually done in small groups or teams whose members need to cooperate so that they can reach their common goal that is to find one or more solutions for the problem, if it has a solution;
- develop communication competences, as they need to read, write, prepare materials, do presentations and discuss, at least, with colleagues and teacher.

These arguments are consistent with, for instance: Dewey's ideas of learning as a social process; Piaget's idea that learning depends on the learner's logic-mathematic reasoning abilities (Piaget, 1979); Vygotsky' idea that learning takes place in social contexts in which the teacher should scaffold the students (Palincsar, 1998; Tan, 2007); Bruner's idea that students learn better by doing (Palincsar, 1998); and Ausubel's idea that the type of learning that matters is meaningful learning which requires knowledge to be integrated into the cognitive structure of the learner (Ausubel, Novak & Hanesian, 1980).

Despite the convincing arguments for PBL, reviews of research focusing on the effects of PBL on science learning (e.g., Albanese, & Mitchell, 1993; Demirel & Dağyar, 2016; Dochy et al, 2003; Leite, Dourado & Morgado, 2016) do not provide unequivocal support for PBL as a teaching approach. In fact, PBL students' conceptual learning results are often similar to the ones attained through conventional methodologies and seldom overcome them. However, there are two aspects in favour of PBL that deserve being stressed: no PBL-based published research was found leading to lower results than the traditional approaches; PBL fosters the development of relevant learning components other than the conceptual one. However, it should be noted that some research studies have methodological limitations (Albanese & Mitchell, 1993; Hung, Jonassen & Liu, 2008; Leite, Dourado & Morgado, 2016) that reduce the credibility of the results attained.

Research on teachers' reactions towards PBL suggests that they fear (Goodnough, 2008; Leite et al, 2013; Morgado, 2016) but (after getting used) enjoy (Vernon, 1995; Dahlgren, Castensson & Dahlgren, 1998; Pepper, 2008; Ribeiro, 2010; Leite et al, 2013; Morgado, 2016) the challenge of trying a very different methodology but they feel unsecure about students' learning (Li & Du, 2015) in a PBL environment. They themselves ask for support from people experienced on PBL in order to get advice on how to deal with the challenge of putting PBL into practice in real classrooms. Besides, research indicates that according to teachers, students' reactions

towards science teaching through PBL depend on students' academic level, with the low achievers (according to teachers' criteria) showing better attitudes than top students (Leite et al, 2013; Morgado, 2016).

As it is well known, PBL started in medical schools (Barrows, 1996; Camp, 1996; Boud & Feletti, 1997; Barret & Moore, 2011; Hmelo-Silver, 2004; Savery, 2006) but it quickly spread to other areas and reached science education, namely in Portugal where the first known paper was written in 2001 (Leite & Afonso, 2001) and the first research was completed in 2001 by Gandra. At the time the research reported in this paper took place, the National Curriculum (DEB, 2001a) as well as the Physical and Natural Science Curriculum Guidelines (DEB, 2001b) did not explicitly mention the use of problems for science curriculum development but they suggested the use of problem-solving in the science classroom (Morgado & Leite, 2011). Nevertheless, they did not make any explicit reference to PBL. However, it seems possible to integrate PBL into science classes without contradicting the spirit of the national curriculum guidelines. This may happen because the guidelines argue for the use of student-centred teaching approaches that give students an active role and that acknowledge their previous knowledge as a starting point for the development of a diversity of competences, ranging from conceptual, to procedural, attitudinal and metacognitive.

Most science teaching in Portuguese schools is still teacher-centred and subject-based. There are a few experiments with PBL focusing on different science topics and school grade levels, organized on a school subject basis (e.g., Gandra, 2001; Carvalho, 2009; Torres, Preto & Vasconcelos, 2013). Despite the reduced sample size, they suggested that students might have benefited from PBL because they achieved better learning results or because they developed competences that their counterparts did not. In addition, a research study carried out by Morgado et al (2016) suggested that PBL organized into a transdisciplinary basis led to better results than the traditional approach when high demanding cognitive questions were at stake but not necessarily in the case of low demanding questions. If this can be confirmed, it would be a strong argument in favour of PBL.

In summary, even though PBL seems to be a powerful approach, research results are not clear enough with regard to PBL effect on science learning, partly due to some research design weaknesses. Besides, some studies did not take into account the multidisciplinary nature of real problems, which requires PBL to be transdisciplinary rather than school subject-centred.

RESEARCH QUESTION

Bearing in mind the disciplinary teacher-centred characteristics of most Portuguese science teaching and the multidisciplinary nature of real life problems, this study aims at comparing a transdisciplinary PBL approach with traditional teaching of the theme 'Safety, Prevention and Quality of Life', with regard to students' learning of science content knowledge; finding out students' opinions on the transdisciplinary PBL approach. According to the official curriculum, this 9th grade theme is supposed to be approached within both Natural Sciences and Physical Sciences school subjects and therefore the two of them were involved in this study.

RESEARCH METHODOLOGY

In Portugal, science education for all children goes up to 9th grade that is to 14/15 years old. Afterwards, students must continue at school but they can choose to study science or not. Thus, this research is centred on the last school grade in which science is taught to all children, which is a relevant stage from a citizen's education point of view. It took place in a secondary school that volunteered to participate in a research project which encompassed the research reported in this paper.

As mentioned above, the science theme chosen for the purpose of this research was 'Safety, Prevention and Quality of Life', which belongs to the syllabuses of two school subjects: Physical Sciences (includes Physics and Chemistry) and Natural Sciences (includes Biology and Geology). Physical Sciences are supposed to cover topics like Basic motion concepts, Collisions, Airbags, Helmets and seat belts, Traffic accidents prevention. Natural sciences are supposed to address issues like Traffic accidents, Effects of alcohol and drugs on the driver's abilities, Driver's food behaviour and psychological characteristics.

A quasi-experimental, pre-/post-test design with control group (see McMillan & Schumacher, 2010) was adopted. Two 9th grade classes and their four teachers were involved in the study even though with different degrees of engagement. Thus, from the experimental group (EG) side, a Physical and a Natural Sciences teacher were involved together with their 24 students. From the control group (CG) side, a Physical and a Natural Sciences teacher were also involved together with their 25 students.

The EG followed an active student-centred transdisciplinary PBL approach. Teachers were invited to work together to approach the topics referred to above, with no differentiation between what used to be the class time periods of each one of the two school subjects. Teaching materials were prepared or selected by the EG teachers and the researchers. To start the PBL sequence, a scenario like a press news focusing on 'Reducing traffic accidents: a matter of safety, prevention and quality of life', was adapted by the two schoolteachers and the researchers. It worked as a context for students to raise problems that would require concepts within the scope of the whole theme if they were to be solved by the students. Both teachers monitored the students, which were asked to work in small groups, each at a time or together, according to their availability and the anticipated students' needs of guidance. One of the researchers observed all the EG classes to give support to teachers.

However, at the end, both teachers assisted to students' presentations and conducted the solution analysis and the process evaluation. Figure 1 gives a synopsis of the process followed in the EG.

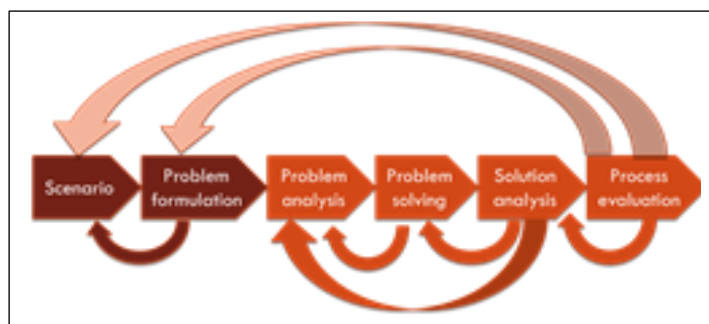


Fig. 1: Synopsis of the PBL approach followed in the EG

The CG followed a disciplinary teacher-centred approach with teachers working separately and with a well-marked differentiation of the two subjects. They followed the assigned textbooks approach, namely with regard to the sequence of the topics and the activities performed in each subject.

Both interventions lasted for about a month. However, in the CG part of the time was devoted to solving exercises after addressing the content.

Inquiry through questionnaire was the data collection technique adopted. Then, to avoid contamination, the researchers alone designed a paper and pencil test to be used as pre- and post-test in the two research groups. The test covers the contents addressed and includes open-ended questions so that students could explain their ideas without being influenced by a given set of predetermined possible answers.

Students answered the test individually, two days before initiating the theme (pre-test) and eight days after concluding it (post-test). Both groups have done it in a Physical Sciences class time, supervised by their own Physical Sciences teacher.

Data analysis included content analysis based on a set of predetermined categories, as follows:

- *Correct answer*: scientifically accepted and complete answer, according to what is expected for this grade level, based on what is prescribed in the syllabus;
- *Incomplete answer*: answer that misses one or more elements required to be considered complete but does not include any incorrect idea;
- *Answer including alternative conceptions*: answer that includes ideas which are not consistent with the scientifically accepted ones;
- *Don't answer*: comprises no answer, incomprehensible answers and answers that simply repeat the question.

Pre-/post-test gains were also computed. They have to do with the difference between the post-test and the pre-test percentages obtained for each category of answer. They indicate a variation that can be either positive or negative and that is good or bad depending on the category that is at stake. A positive gain is desirable for the correct answer category and a negative gain is desirable for the Don't answer category. For the other categories, the interpretation of the gain in a category depends on the gains in the other categories. Finally, to attain the objective of the study, control group *versus* experimental group comparisons were made.

Afterwards, a more detailed analysis was performed in order to get more information on the incomplete answers and the ideas that were more and less hard for students to acquire.

In a physical sciences class after the post-test, the EG students were asked to answer to an opinion questionnaire on the PBL approach. The questionnaire, composed of 15 directional Likert type items, had been developed previously by Leite, Dourado & Esteves (2011). The scale used was a five degrees scale ranging from *Nothing* to *A lot*. Frequencies per item and scale grade were computed in order to get information on issues that deserved more and less positive reactions from the EG students.

RESEARCH RESULTS

Students' learning

Table 1 shows the results relative to students' science content knowledge learning which were collected through a test used as pre- and post-test in both research groups (EG and EC). In the pre-test, no research group reached a correct answer in any question. In the post-test, correct answers were obtained in one question (question 3) only.

Table 1: Control/experimental gains comparison for questions asking for an explanation (%)
(N=49)

Question	Group	Correct		Incomplete		Including AC		Don't answer	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
1 - Driving under alcohol	CG	0,0	0,0	96,0	92,0	4,0	4,0	0,0	4,0
	EG	0,0	0,0	75,0	91,6	25,0	8,3	0,0	0,0
2 - Driving under drugs	CG	0,0	0,0	84,0	96,0	16,0	0,0	0,0	4,0
	EG	0,0	0,0	83,3	87,5	12,5	0,0	4,2	12,5
3 - Slow down motion	CG	0,0	4,0	24,0	44,0	4,0	20,0	72,0	24,0
	EG	0,0	29,2	20,8	16,7	12,5	20,8	66,7	33,3
4 - Speed and velocity	CG	0,0	0,0	0,0	4,0	36,0	44,0	64,0	52,0
	EG	0,0	0,0	0,0	70,8	33,3	4,2	66,7	25,0
5 - Asleep driver after lunch	CG	0,0	0,0	28,0	44,0	72,0	44,0	0,0	12,0
	EG	0,0	0,0	45,8	62,5	50,0	37,5	4,2	0,0
6 - Instantaneous velocity <i>versus</i> mean speed	CG	0,0	0,0	12,0	24,0	8,0	0,0	20,0	60,0
	EG	0,0	0,0	20,8	58,3	8,3	0,0	70,8	41,7
7 - Collisions on a road	CG	0,0	0,0	28,0	40,0	8,0	8,0	64,0	52,0
	EG	0,0	0,0	42,2	54,2	4,2	0,0	53,6	45,8

Note: n_{EG} = 25; n_{CG} = 24

Table 2 shows the gains (positive, null or negative) for the seven questions used to assess students' learning in this research study. An analysis of the gains obtained for the correct answers shows that non-null gains were obtained for question 3, the only got correct answers. Those gains are positive for the two research groups. However, the gains obtained for the EG (29,2%) are much larger than those obtained for the CG (4,0%) which is a result in favour of the EG.

Table 2: Control/experimental gains comparison for questions asking for an explanation (%)
(N=49)

Question	Correct		Incomplete		Including AC		Don't answer	
	CG	EG	CG	EG	CG	EG	CG	EG
1 - Driving under alcohol	0,0	0,0	-4,0	16,6	0,0	-16,7	4,0	0,0
2 - Driving under drugs	0,0	0,0	12,0	4,2	-16,0	-12,5	4,0	8,3
3 - Slow down motion	4,0	29,2	20,0	-4,1	16,0	8,3	-40,0	-33,4
4 - Speed and velocity	0,0	0,0	4,0	70,8	8,0	-29,1	-12,0	-41,7
5 - Asleep driver after lunch	0,0	0,0	16,0	16,7	-28,0	-12,5	12,0	-4,2
6 - Instantaneous velocity <i>versus</i> mean speed	0,0	0,0	12,0	37,5	-8,0	-8,3	-4,0	-29,1
7 - Collisions on a road	0,0	0,0	12,0	12,5	0,0	-4,2	-12,0	-7,8

Note: n_{EG} = 25; n_{CG} = 24

Then, an analysis of the gains for the incorrect answers shows that: no null gains were obtained; larger positive gains were obtained for the experimental group in three questions (question 1, 4 and 6); similar positive gains were obtained for questions 5 and 7; lower gains were obtained for the EG in question 2 and 3. However, if in the case of question 3 we sum up the gains obtained for the correct and incomplete answers, for each group, 24,0% and 25,1% will be obtained for the CG and the EG, respectively. Even though these two percentages are similar, the 25,1% of the EG are better because they come mainly from complete answers while the 24% of the CG come mainly from incomplete answers. Data given in table 2 also show that positive gains in the complete and incomplete answers are associated with negative gains in the Don't answer and/or Including Alternative Conceptions (AC) answer. Thus, it can be stated that the EG achieved better results than their counterparts in the CG.

As far as the incomplete answers are concerned, table 3 shows that in question 1 the CG incomplete answers were more incomplete than those of the EG as the percentage of incomplete answers mentioning 2 or 3 effects that alcohol can have on a driver's organism is much larger in the EG (40,9%) than it is in the CG (26,1%). Being the numbers of students similar in both groups (22 and 23, respectively), this result is also in favour of the EG.

Table 3: Driving under the effect of alcohol - # of effects in Incomplete Answers (%)

# effects mentioned	Pre-test		Post-test		Gains	
	CG (n=24)	EG (N=18)	CG (n=23)	EG (n=22)	CG	EG
1	87,5	83,3	73,9	59,1	-13,6	-24,2
2 or 3	12,5	16,7	26,1	40,9	13,6	24,2
4 or 5	0,0	0,0	0,0	0,0	0,0	0,0

Table 4 shows that the two research groups mentioned the same effects of the alcohol, in the pre- and the post-test, the only exception being the EG that did not mention sleepiness, in the pre-test. ‘Difficulty of risk assessment’ was the effect mentioned by larger percentages in the pre-test probably because it has to do with every day (including mass media) arguments against drink ingestion before driving.

Table 4: Driving under the effect of alcohol - Effects mentioned in Incomplete answers (%)

Effects	Pre-test		Post-test	
	CG (n=24)	EG (n=18)	CG (n=23)	EG (n=22)
Reduction on the reaction capacity	25,0	27,8	65,2	63,6
Difficulty of risk assessment	50,0	61,1	34,8	54,5
Sleepiness	20,8	0,0	8,7	9,1
Vision limitations	20,8	27,8	17,4	22,7
Motor coordination limitations	0,0	0,0	4,3	9,1

Percentages relative to ‘Reduction on the reaction capacity’ and to ‘Motor coordination limitations’, increased from the pre- to the post-test, being a bit favourable to the CG in the former case and to the EG in the latter case. These effects have to do with human physiology (Ogden & Moskowitz, 2004; Carson-DeWitt, 2003) and the increase in the percentages from pre- to post-test may mean that learning took place in both groups.

Table 5 shows that in question 2 the CG incomplete answers were quite as incomplete as those of the EG, as the percentage of incomplete answers mentioning 2 or 3 effects of drugs on a driver’s organism is quite as large in the EG (28,6%) as it is in the CG (29,2%). It should be emphasised the CG students that had mentioned 4 or 5 effects in the pre-test did not mention the same number of effects in the post-test. Therefore, these results are not clearly in favour on any of the groups.

Table 5: Driving under the effect of drugs - # of effects in Incomplete Answers (%)

# effects mentioned	Pre-test		Post-test	
	CG (n=21)	EG (n=20)	CG (n=24)	EG (n=21)
1	85,7	95,0	70,8	71,4
2 or 3	9,5	5,0	29,2	28,6
4 or 5	4,8	0,0	0,0	0,0

Data given in table 6 show that the most mentioned effects in Incomplete answers relative to the effects of drugs on the driver compare to those most mentioned for the alcohol question (see table 4). However, the control group added a new effect in the pre-test that is hallucinations, which is also mentioned by authors like Ogden and Moskowitz (2004) and Carson-DeWitt (2003). In the EG, from pre- to post-test, percentages increased for all effects except for ‘Difficulty of risk assessment’. In the control group, the percentages obtained for several effects decreased a little bit. The ‘Reduction on the reaction capacity’ was again the effect whose percentages suffered a larger increase as it happened in the case of alcohol (see table 3). This increase was larger for the EG.

Table 6: Driving under the effect of drugs - Effects mentioned in Incomplete answers (%)

Effects	Pre-test		Post-test	
	CG (n=21)	EG (n=20)	CG (n=24)	EG (n=21)
Reduction on the reaction capacity	28,6	10,0	50,0	61,9
Difficulty of risk assessment	47,6	85,0	41,7	57,1
Sleepiness	9,5	0,0	4,2	4,8
Vision limitations	14,3	5,0	8,3	14,3
Motor coordination limitations	0,0	5,0	0,0	9,5
Hallucinations	28,6	0,0	25,0	4,8

Question 3 asked students to explain why a child (Rui) traveling without the car seat belt fasten was project forwards and hit the head when his father slowed the car down due to meeting a red traffic light, in a raining day. Table 7 shows that each incomplete answer for this question includes one of two explanations. The first explanation is a synthetic statement that does not provide fully evidence that their holders really understand what they are saying. This interpretation is supported by answers like the following one: “His seat belt was not fasten and a body that is moving tends to keep on motion” (post-test, CG11). The first part of this answer is a repetition from the question (the seat belt was not fasten) which is not explicitly related to the second part of the answer, which is a general statement (on the inertia law), not explained.

Table 7: Motion when slowing down - Explanations in Incomplete answers (%)

Explanation	Pre-test		Post-test	
	CG (n=6)	EG (n=5)	CG (n=11)	EG (n=4)
Rui's body tends to continue in motion	0,0	20,0	63,6	0,0
As Rui's seat belt was not fasten, there was nothing to prevent him from keeping moving with the car speed at the slow down instant	100,0	80,0	36,4	100,0

The second one is much more explicit in terms of why Rui was projected. In fact, it implicitly mentions the role of the seat belt (it would prevent Rui from keeping moving with the car speed), as shown by the following answer: “As a force was exerted on the car, it stopped; as no force was exerted on Rui, he kept on moving” (post-test, EG18). In the post-test, all the incomplete EG answers fell into this category, while the same happened with only about one third of the CG incomplete answers.

Question 4 focused on Rui's conversation with his father; Rui was talking about the car speed and his father talking about the car velocity. Table 8 shows that incomplete answers relative to a possible difference between the meanings of the two words were registered in the post-test only and that they fell into three categories.

While the CG incomplete answer fell into the most incomplete group of answers, the EG incomplete answers are distributed by the three categories, being some of them (11,8%) quite complete, which is an indicator of deeper learning. An example of this is the following answer, which combines type of magnitude and trajectory: “Velocity is the distance (straight line) between points A and B (displacement) over a certain time; speed is the path travelled between points A and B over a certain time.” (post-test, EG18). Bearing in mind table 1, the incomplete answers are a result of a reduction in Including Alternative Conceptions and/or Don't know answers. Therefore, data in table 8 reinforce the idea of a better performance of the EG.

Table 8: Speed and velocity - Explanations in Incomplete answers (%)

Explanations	Pre-test		Post-test	
	CG (n=0)	EG (n=0)	CG (n=1)	EG (n=17)
Velocity is a vector magnitude and speed is a scalar magnitude	0,0	0,0	100,0	52,9
Velocity is a ratio between the displacement and the time spent to make it; speed is a ratio between the path covered and the time used to cover it.	0,0	0,0	0,0	35,3
Velocity is a ratio between the displacement and the time spent to make it; speed is a ratio between the path covered and the time used to cover it. Then, opposite to speed, velocity does not depend on the trajectory.	0,0	0,0	0,0	11,8

When explaining why a truck driver fell asleep after lunch, having slept well the night before (question 5), students mentioned only one of the two issues that would be demanded to them according to the syllabus. Thus, they based their explanation either on ‘Digestion energy requirements’ or on ‘Blood concentration on stomach and intestine’ (table 9), which are effects that are mentioned in the literature (Barr & Wright, 2010; Eldelstone & Holzman, 1981). The former was the most popular in both research groups, in the pre- as well as in the post-test. Surprisingly, a few students of the EG abandoned the explanations based on the idea of ‘Blood concentration on stomach and intestine’. In the whole, these results are consistent with those given in table 1, as they are not in favour of none of the research groups.

Table 9: Driving when feeling asleep after lunch - Explanations in Incomplete answers (%)

Explanation	Pre-test		Post-test	
	CG (n=7)	EG (n=11)	CG (n=11)	EG (n=15)
Digestion energy requirements – needs energy and originates a deficit in the rest of the body	85,7	45,5	100,0	86,7
Blood concentration on stomach and intestine – brain has not enough blood to react	14,3	54,5	0,0	13,3

Question 6 focuses on who was right: a driver, arguing that he made calculations (with time and km) and was moving at 100km/h, and a police officer, accusing the driver of having exceeded the maximum velocity (or instantaneous speed, that is equal to instantaneous velocity magnitude) limit of 120km/h. Table 10 shows that three types of incomplete explanations were obtained, being the first one a statement that does not make explicit the difference between the two concepts that are at stake: instantaneous velocity and mean speed.

Table 10: Instantaneous velocity vs mean speed - Explanations in Incomplete answers (%)

Explanation	Pre-test		Post-test	
	CG (n=3)	EG (n=5)	CG (n=6)	EG (n=14)
Mean speed is different from instantaneous velocity	0,0	0,0	16,7	0
The value shown by the policy radar has to do with instantaneous velocity	33,3	0,0	16,7	0
The driver's argumentation is wrong because it is based on the computation of the speed and this is not what the radar shows.	66,7	100,0	66,6	100,0

Even though many incomplete answers were got in the post-test for the EG, they not only resulted from a decrease in the Alternative conceptions and Don't know answers but also fell into the most complete group of incomplete explanations. This group shows disagreement with the driver's reasoning, uses the concept of mean speed and implicitly or explicitly suggests that the radar does not shows that magnitude. This can be illustrated by the following answer: "The car driver calculated the mean speed [100km/h] but he may have exceeded the velocity limit [120km/h] even though the mean was that one." (post-test, CG25).

Table 11 shows that the number of Incomplete answers increased in both research groups from pre- to post-test, for question 7. This question focuses on the effects of two cars colliding with the road protection rails. In one of the collisions, the rails were damaged but not broken; in the other collision, the rails were broken. The two explanations obtained for incomplete answers suggest that students seem to focus on the observable effects rather than on the interaction between the cars and the protection rails. Nevertheless, it seems that the second explanation given in table 11, shown by less students in both groups, is a bit more complete than the first one. In fact, the second explanation relates force, speed and collision effects, as illustrated by the following answer: "To break the protecting rails a large force is needed; this means that it was travelling with a larger speed." (Post-test, EG15). These results suggest that the numbers of students showing the most complete answer did not change from pre- and to post-test.

Table 11: Collision on a road - Explanations in Incomplete answers (%)

Explanation	Pre-test		Post-test	
	CG (n=7)	EG (n=10)	CG (n=10)	EG (n=13)
The larger the magnitude of the impact force, the more violent is the collision	85,7	80,0	80,0	92,3
The larger the speed, the larger the magnitude of the impact force and the strongest is the effects of the collision	14,3	20,0	20,0	7,3

EG students' opinions on PBL

The EG students' opinions on PBL were collected through an opinion questionnaire, after the post-test. Table 12 shows the questionnaire 15 items, clustered according to the skills that underlie them, and the frequencies obtained for each grade of the scale.

Table 12: EG students' opinions on the PBL approach (f)

(N=24)

Skills	Items	Nothing	A little bit	Moderately	Quite a lot	A lot
Learning	13. Deepen knowledge/ideas	0	0	7	9	8
	14. Understand content	0	5	4	10	5
	12. Learn about issues that interest to me	0	3	7	8	6
Problem-solving	10. Learn how to solve problems	0	1	4	15	4
	8. Learn how to plan tasks	0	2	4	14	4
Thinking	11. Learn how to synthesize	0	2	5	13	4
	7. Learn to think	0	2	2	12	8
	5. Learn how to interpret information	0	0	9	11	4
Communication	3. Learn how to communicate ideas	0	3	3	14	4
	4. Learn how to present own ideas	0	2	6	14	2
	1. Learn how to argue and counter-argue	0	2	9	11	2
Social interaction	6. Learn how to share tasks	0	1	7	15	1
	2. Learn how to cooperate with colleagues	0	0	4	14	6
	9. Learn how to respect the others' opinions	0	0	7	12	5
Welfare	15. Feel comfortable	2	5	8	4	5

An analysis of the frequencies given in this table shows that at least two thirds (that is 16) of the 24 students choose the Quite a lot or A lot degrees for 10 (out of 15) items. Item 15 was the only item that got non-null frequencies for the Nothing degree and about one-third only for Quite a lot plus A lot, meaning that some students did not feel comfortable with PBL classes. This sensation may be due to students' initial lack of experience with not only PBL but also with teamwork and with enquiry like tasks, as well as with their high level of anxiety regarding the non-distinction between the two disciplines and the nonexistence of exercises to be solved by (and after) the end of the classes. Thus, it seems that the novelties introduced may have really caused initial discomfort to students. Nevertheless, for what researchers and teachers could observe, most of them overcame those difficulties and anxiety quite fast. An additional evidence of this is that the discomfort felt did not impair them from recognising the positive things they got from the PBL approach. Excluding item 15, items 1 and 12 are the ones that got less Quite a lot and A lot. In the former case, on one hand, it should be noted that argumentation is not an easy competence to develop (Belland, Glazewski & Richardson, 2008) and, in the other hand, it may happen that students were not familiar with the words, especially with counter-argumentation. It may be that argumentation and counter-argumentation competences development may need more assistance from the teacher than the PBL context provided. In the latter case (item 12), it should be emphasized that what students learned was limited by the problems that emerged from the scenario. During the classes, teacher(s) were used to monitor the small groups' activities in order to check whether they were on the task or whether they were doing other things. It was necessary to settle strict rules for internet access in order to prevent waste of time with issues that were not relevant for the task students had at hands. In fact, undue internet use was an expected issue (see Dogruer, Eyyam & Menevis, 2011) as it was students' unhappiness with limitations on this. On the other hand, as argued above, the fact that the Portuguese curriculum is not a problem-based one, obliged teachers and researchers to find problems to be solved that were consistent with the curriculum demands, as the use of a new methodology and the undertaking of a research experience could not prevent the compulsory curriculum to be followed.

CONCLUSIONS AND IMPLICATIONS

The global results together with the incomplete answer analysis suggest that students in the EG performed better than their CG counterparts, which is a result consistent with studies that compared PBL with traditional teaching (ex. Gandra, 2001, Carvalho, 2009; Khoshnevisasl et al, 2014; Zahid et al, 2016; Strobel & van Barneveld, 2009; Morgado et al, 2016). However, both groups rarely reached complete answers, which may be partly due to strict correction criteria adopted in this research and partly due to language issues. The latter may be especially true for physics questions that deal with the speed and velocity concepts, as the words that give names to these two physics concepts are usually used undistinguishably in Portuguese everyday language. Besides, even though the EG students may have felt an initial discomfort (as it happened in other studies – see, for example, Gandra, 2001; Selçuk, 2010; Alessio, 2004; Larin, Bucciari & Wessel, 2010), they seem to have valued PBL as they recognized that they have developed several types of competences.

Thus, the use of a transdisciplinary approach neither impaired students from learning nor made them feel confused and unhappy. However, the fact that some students (not only but also in the EG) used a sort of slogan-like explanations when trying to explain their reasoning on issues related to daily life situations should deserve

attention. On one hand, pedagogic attention is needed in order to find better ways of promoting deep learning. Hence, results obtained through the present study should be combined with those obtained by Morgado et al (2016) in order to find ways of making PBL more useful for the learning of students' complex and familiar issues. On the other hand, research attention is needed in order to find out whether slogan-like answers just happened or whether this is a result consistent with what Silva, Leite and Pereira (2013) found with seven graders, which were asked to solve familiar problems.

This concern raises a few questions that are worth considering. Were students happy with their previous common sense knowledge about the effect of drugs and alcohol on the organism so that they did not feel the need to learn more about it? Should the teaching context have been able to deal with such knowledge to show that it is not enough to fully explain the situation? Was inertia law too much emphasized so that students memorized it and, maybe, based on previous experiences, felt that it would be enough to restate the law without explicitly relating it to the problem-situation that was at stake? Of course it may also have happened that the information sources used by the students were reinforcing the slogan-like answers or that they were unable to propel students to go deeper into the issue. Answering to these questions would be useful for organizing learning situations more able to foster students' deep learning through PBL.

Finally, bearing in mind that EG students managed well with transdisciplinary PBL, it should be investigated how disciplinary and transdisciplinary PBL convey students the ability to deal with real problems which are transdisciplinary in nature. Transdisciplinary PBL is more demanding for teachers and school organization. From the authors' experience, teachers need to get not only training but also support from researchers or colleagues used to PBL as well as from the school director. PBL requires flexible classroom organization and school resources use which need to be acknowledged by the whole school. Effort to get such support may be worthwhile as PBL seems to be one of the best teaching approaches for XXIst century students, which need to be prepared for solving real problems. As it was argued elsewhere (Leite et al, 2017; p.159.), PBL can "show students that science [...] is all around them and that the knowledge it encompasses may help them not only to better understand, fully appreciate and respect more the natural world but also to take more advantage from what the natural world can offer without putting it at risk."

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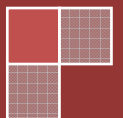
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Factor of Values Influencing Mind Virtue of Muslim Malay Youth: Study in Klang Valley, Malaysia <i>JAWIAH Dakir, SITI MASLIAH Mohd Nuri, FARIZA Md Sham, Khairul Anwar MASTOR, SITI RUGAYAH Hj TibeK, A'DAWIYAH Ismail, AL ADIB Samuri, JALIL M. H., NOOR AZIAH Mohd. Awal</i>	1
Factors Analysis of Technology Leadership in Thailand Royal Awarded School <i>Dawruwan THAWINKARN</i>	7
Fluorescence of Edible Oils in Teaching the Course Forensic Science <i>Michaela MIKULIČOVÁ, Vojtěch KŘESÁLEK</i>	16
From Learning to Practice: A Draft of Access to Optimize the Structure of University Studies Taking Into Account Specifics in Arts Oriented Schools <i>R. ČOČKOVÁ, O. JURÁŠKOVÁ</i>	22
General Principles of Shaping Teaching Content For Informatics As A Teaching Subject <i>Jiří DOSTÁL, Jiří KROPÁČ</i>	34
Global Competencies of Undergraduate Students in Dentistry, Nursing and Engineering Programs <i>Unchalee SANRATTANA, Suwadee AERARUNCHOT, Pavee SIRIRUK, Somsamorn RUEANGWORABOON</i>	41
Google Slide As a Tool to Promote Active Learning Strategies <i>Dawood Al HAMDANI</i>	50
Graphical Solution of Linear Programming Problems in MS Excel <i>Anna NEBESOVÁ, Jana SEKNÍČKOVÁ</i>	56
Happiness of Students' Suan Sunandha Rajabhat University <i>Pimporn THONGMUANG</i>	63
How the Cipp Model Assesses the Entrepreneurial Education Program: From the Micro Entrepreneurs' Perspective <i>Tengku Maaidah Tengku A RAZAK, Muhammad Sabri HARON, Nor Aishah BUANG</i>	70
How to Teach Mathematics: Some Suggestions from Herbartian Tradition <i>Verena ZUDINI</i>	79
Impacts of Differentiation of Self on Interpersonal Relationship in Early Adulthood: Mediating Roles of Adult Attachment and Empathy <i>Dalsaem BAE, Min-hee KĪM</i>	83
Implementation Managing Strategic for Innovation in High Vocational Education Systems (Hves): From Malcolm Baldrige National Quality Award (Mbnqa) for Improving Competitiveness of Graduates <i>Budhi HARYOTO, MARDJI, DARDIRI, Eddy SUTADJI</i>	91
Implementing Numbered Heads Together Strategy to Year 5 Students: An Alternative Approach to Teaching Writing <i>Sri Kartika A.Rahman, Harinah Mohd Shara, Suraya Tarasat, Noradinah Jaidi</i>	98
Implication of Model of Acceptance and Behavior Usage of Mobile Learning in Higher Education of Indonesia <i>Syamsul Arifin, Aulia Siti Aisjah, Punaji Setyosari</i>	105
Importance of Architecture for the Success of Primary Education <i>Arzu CAHANTIMUR, Rengin BECEREN OZTURK</i>	112
Importance of the Role of Education on Basic Problems of Measuring and Determining Costs in the Company <i>Zuzana CHODASOVÁ, Mária ĎURIŠOVÁ, Alžbeta KUCHARČÍKOVÁ, Zuzana TEKULOVÁ</i>	117
Improved Learning Through Interactive Video Mini-Lectures in Ecology	126

In the Footsteps of de La Salle, On Becoming a Lasallian: Evaluation of the Conduct of the Intro to La Salle and Contextualization and Living out the Lasallian Guiding Principles Sessions for All Incoming First Year and Second Year Students of Dela Salle Health Sciences Institute <i>Juanito O. CABANIAS</i>	132
Increasing the Success Rate in Mathematics at the College of Polytechnics Jihlava (Czech Republic) as a Result of the Implementation of Support Measures <i>Martina ZÁMKOVÁ, Martin PROKOP, Radek STOLÍN</i>	142
Industry and Vocational Education <i>Ismail BECENEN</i>	151
Influence of Experiential Education in Pre-Graduate Training of Teachers on the Classroom Climate – The Conflicts <i>Renata OROSOVA, Katarina PETRIKOVA</i>	155
Information Literacy Level of Coastal and Small Island Community in Indonesia on Accepting the Education of Technology with Animation Base <i>Ira Maryati</i>	163
Initiative Taking Levels of School Principals* <i>Naciye Denizer, F. Sülen Şahin Kıralp</i>	171
Innovation of Education in Risk and Crisis Management <i>Katarina BUGANOVÁ, Valéria MORICOVÁ</i>	177
Innovative Technologies in Educational Process of Teaching Computer Graphics <i>Zamirgul KAZAKBAEVA, Kamchybek SYDYKBEKOV</i>	183
Integrated Moral Values in Standard-Based Assessment: Opportunities and Challenges of Computer-Based Test in Indonesian National Assessment <i>Bambang SURYADI, Yuli RAHMAWATI</i>	187
Integrating Assessment For Learning Strategies Into Online Learning Environments: A Case Study Of Teaching Secondary Ict <i>Yiu Chi LAI</i>	200
Integrating Software Development Courses in the Construction Curriculum <i>Afolabi, ADEDEJI, Ojelabi, RAPHEAL, Oyeyipo, OPEYEMI, Tunji-OLAYENI, PATIENCE, Omuh, IGNATIUS, Amusan, LEKAN</i>	215
Integration of Landscape Analysis and Assessment Methods, into Vocational Education Processes of Design and Planning Disciplines, by using R & D Projects <i>Gül Aslı Aksu</i>	226
Integration of Social Innovation Creation in Higher Education: Case Study of Latvia <i>Andra ZVIRBULE, Gunta GRINBERGA-ZALITE</i>	235
Interaction and Communication in Education at the University: Temporal Aspect of Educational Communication and Activities and Forms of Communication <i>Michaela LUKEŠOVÁ</i>	241
INTERACTIVE EFFECTS OF ENGLISH PROFICIENCY AND MATERIAL PRESENTATION MODE ON ENGLISH LISTENING COMPREHENSION AND COGNITIVE LOAD IN MOBILE LEARNING ENVIRONMENT <i>Chi-Cheng Chang & Hao Lei</i>	247
Intercultural Peculiarities of Modern American Movie Translation <i>Zhumaliyeva RAKHIMA</i>	253

Internationalization of Higher Education Institutions: The Case Study of the Polytechnic Institute of Bragança <i>Cláudia Miranda VELOSO, Paula Odete FERNANDES</i>	260
Investigating Ethical Information Sharing in Facebook Within Educational Context Through Adopted Papa Framework <i>Seren BAŞARAN</i>	268
Investigating Formative Assessment Strategy to Chemistry Habits of Mind (Chom) of Buffer Solution Concept in Learning Chemistry <i>NAHADI, Sjaeful Anwar, Dewi Kharisma WINDANI</i>	276
Investigation of Healthy Living Behaviors of University Students Participating and Non Participating Sports <i>Selma CİVAR YAVUZ, Nazmi BAYKÖSE, Ömer ÖZER, Ahmet ŞAHİN, Meryem ÇOBAN</i>	286
Investigation of Preservice Elementary Teachers' Opinions on Science Fiction Films <i>Ümit İZGİ</i>	293
Investigation of Relationship between Factors Hindering the Participation of University Students in Recreational Activities and their Leisure Motivations Levels <i>Fatih UZUN, Osman PEPE, Mehmet Behzat TURAN</i>	298
Investigation of Teacher Opinions on Measurement Tools Used to Evaluate Listening/Monitoring Skills <i>Zeynel HAYRAN</i>	304
Investigation of The Factors Influencing Teaching Profession Choices of Pedagogical Formation Trainees <i>Volkan PAN, Serkan SAY</i>	311
Investigation of the Relationship Between University Students' Personal Characteristics and Success Tendencies <i>Mehmet Behzat TURAN, Barış KARAOĞLU, Kenan KOÇ</i>	318
Investigation of the Subjective Well-Being of Psychological Counselling Candidates and The Perceived Social Support Levels <i>Seda TÜRKÖZ</i>	326
Investigation on The Effect of the College Curriculum Of Physical School College of Physical Education on Communication Skills <i>Alper TANRIKULU, Kuddusi KILIÇ, Mehmet Behzat TURAN, Kerimhan KAYNAK</i>	337
Kaizen and Intuition in Stress Management <i>Okan ŞENELDİR, Sinan AYDIN, Mustafa KUDU, İsmail KILIÇARSLAN, Mustafa OF, Celal MUTLU</i>	345
Knowledge and Skills Transfer for Sustainable Rural Tourism in the Baltic Sea Countries <i>Gunta GRINBERGA-ZALITE, Zane VITOLINA, Baiba RIVZA</i>	350
Knowledge Management Model to Develop Creative Thinking for Higher Education With Project Based Learning <i>Kwanjai DEEJRING</i>	355
Korean High School Student's Perception of Trust in Teachers <i>Ryumi Choi, Daehyun Kim</i>	360
La Fete De La Francophonie and Intercultural Communication of French University Students in Indonesia <i>Sri Harini Ekowati</i>	366

Leading Software Development Methodologies in Central Europe <i>Veronika VESELÁ</i>	370
Learning About Safety, Prevention and Quality of Life Through PBL: Implications for Teacher Education <i>Laurinda LEITE, Luís DOURADO, Sofia MORGADO, Manuela VALE, Carla MADUREIRA</i>	375
Learning Adequacy of Nigerian Tertiary Educational System for Sustainable Built Environmental Course <i>R.OJELABI, A.AFOLABI, P.TUNJI-OLAYENI, I.OMUH</i>	387
Learning Difficulties in the Study of Structural Analysis in Tertiary Institutions Ignatius O. OMUH, <i>Lekan M. AMUSAN, Rapheal A. OJELABI, Adedeji O. AFOLABI, Patience F. TUNJI-OLAYENI</i>	395
Learning for Placement.Fostering Innovation in the Construction Sector Through Public-Private Partnership in the Emilia-Romagna Region <i>Marcello BALZANI, Fabiana RACO, Theo ZAFFAGNINI</i>	404
Learning Geometry Through Mathematical Modelling: An Example With Geogebra <i>Maria Giovanna FRASSIA, Annarosa SERPE</i>	411
Learning Programming From Scratch <i>Monika MLADENVIĆ, Divna KR PAN, Saša MLADENVI</i>	419
Learning Strategies Enhancing on Statistical Education <i>Somruay APICHATIBUTARAPONG</i>	428
Learning the Phonetic of Ffl by Turkish Learners: Need for Specific Teaching Materials <i>Fatma KAZANOĞLU, Havva ÖZÇELEBİ</i>	432
Lifelong Learning Tendencies of Primary Education Teachers <i>Nuray KURTDEDE FİDAN, Nuray YILDIRIM</i>	440
Limitations of Peace Education in Divided Societies: The Case of Cyprus <i>Dilek LATIF</i>	447
Listening Comprehension in French Language Teaching – The Situation at Secondary Schools in the Czech Republic <i>Michaela MÁDLOVÁ</i>	453
Looking for New Models of Society: The Example of the Fencing Team <i>Sara NOSARI</i>	460
Managing Universities: From Collegiality to Shared Governance <i>Erman M. DEMİR</i>	465
Masters in Hydraulics:Sense of Humanism in Classrooms Based on Freedom Research? <i>Maritza Liliana Arganis JUAREZ, Juan Jose Baños MARTINEZ, Ramón DOMÍNGUEZ, Eliseo Carrizosa ELIZONDO</i>	469
Measurement of the Human Capital Efficiency – An Interesting Topic For Diploma and Doctoral Theses <i>Alžbeta KUCHARČÍKOVÁ, Zuzana CHODASOVÁ, Mária ĎURIŠOVÁ</i>	474
Measures in Forming a Harmonious Family Based on the Practice of Noble Values Among the Participants of <i>Bicara Sakinah</i> (Talk on Harmony) at <i>Pusat Islam</i> (Islamic Centre), Kuala Lumpur <i>A'dawiyah ISMAIL, Siti Syarah M. TAWIL, Jawiah DAKIR</i>	482
Measuring Robustness of Thai Athletes Using Trait Robustness Of Self-Confidence Inventory (TROSCI)	489

Sarstrawit WONGBUTLEEWATTHANA

Mental Health and Marital Violence <i>Sofia CAMPOS, Conceição MARTINS, Marisa PINTO, Manuela FERREIRA, Cláudia CHAVES, Rosa MARTINS</i>	495
Metamorfosa Kupu-Kupu Song: Integration of Language and Science Subjects for Developing Early Childhood Education Teachers Competences in Teaching Scientific Concepts <i>Tuti Tarwiyah Adi</i>	503
Middle School Students Views' on Socio-Scientific Issues: Global Warming Example <i>Murat GENÇ, Tülin GENÇ</i>	510
Mobile Learning Perception Scale: A Short Version for the Italian Context <i>Samuele ZAMINGA, Gloria GUIDETTI, Rosa BADAGLIACCA, Ilaria SOTTIMANO, Sara VIOTTI, Daniela CONVERSO</i>	516
Model of Project-Based Learning on Cloud Computing Technology in Collaboration to Enhance Ict Literacy <i>Thiti JANTAKUN, Thada JANTAKOON</i>	523
Model Situations for Usage of Creative Techniques While Listening to Modern Popular Music at School <i>Veronika ŠVONCOVÁ</i>	530
Modelling Smartphone Security Behaviour of University Students <i>Mohamad Noorman MASREK, Ismail SAMADI, Qamarul NAZRIN, Atikah AZRY</i>	537
Moral Reasoning of Adolescents <i>Blandina ŠRAMOVÁ</i>	546
Morphological and Contextual Clues in Guessing Word Meaning from Context in a Foreign Language <i>Berrin MANGA ÇETİNAVCI, Meral ÖZTÜRK</i>	552
Motivation of Gifted Pupils Towards Negative School Performance <i>Ilona KOČVAROVÁ, Eva MACHŮ, Adéla VÁLKOVÁ</i>	560
Motivational Factors in Homework: Parent's Strategies <i>Barbora PETRŮ PUHROVÁ, Jana MAJERČÍKOVÁ</i>	566
Multi-Dimensional Expansion of Algo-Rythmics <i>Erika OSZTIÁ, Zoltán KÁTAI, Géza-Károly VEKOV</i>	573
Multiple Drug Use in Elderly and Responsibilities of Nurses <i>Didem SARIMEHMET, Sevilay HİNTİSTAN, Nurhan GÜMRÜKÇÜOĞLU</i>	579
Museum-Based Education as A Part of School Education <i>Kinga Anna GAJDA</i>	584
National Cultural Identity in Teaching English to Kazakhstani Learners <i>Gulnara KASSYMOVA</i>	591
Need Assessment on Teaching and Learning About Water Resource Management and Water Disaster of Basic Education <i>Chunwadee CHUNRASAKSAKUN, Unchalee SANRATTANA</i>	596
Needs Assessment on Knowledge Regarding The Use of ICT Network of the Community Members For Self-Development <i>Intira ROBROO</i>	604

Negative Effects of Barriers to Seeking Psychological Help and Their Association With Depression, Anxiety, Stress, and Self-Efficacy Among College Students <i>Nursel TOPKAYA, Ertuğrul ŞAHİN, Yaşar BARUT</i>	609
New Approach to Entrepreneurship Education in Primary Schools: The BGENTL <i>Teresa PAIVA, Pedro TADEU</i>	618
Non-Profit Management Education in Kazakhstan <i>Bakhytnur OTARBAYEVA</i>	626
Old Meets New: Collaborative Digital Storytelling for Effective 12 Reading Instruction <i>Meliha R. ŞİMŞEK</i>	631
On In-Struction-Ability Of Tacit Knowledge As Ordinary, Practical Member's Method <i>Minho SHON, Hyunyoung CHO</i>	639
On the Level of Academic Achievement of the Vocational School Students: The Effect of Motivation <i>Sinan AYDIN, Yaşar GENEL, Kazım KAHRAMAN, Yusuf TOLA, Mustafa OF, Celal MUTLU</i>	653
On The Way Towards Career Awareness: Interview With Graduates <i>Zehranur KAYA, Meltem Ozten ANAY, Guzin KARASU, Gokçen ABALI, Mehmet Cem GIRGIN</i>	658
Opinions Of Education Administrators Regarding The Impact Of Their Leadership Features On The Mobbing And Organisational Commitment Of Teachers <i>Togay ULUÖZ, Emete YAĞCI, Ali AKTEPEBAŞI, Figen Yaman LESİNGER</i>	670
Opportunities of Interactive Teaching in the Implementation of Project Method <i>I.V. Kovalev, Y.Y. Loginov</i>	680
Outside the Box: Change – Various forms of Connecting Practitioners in the Process of Intensive Kindergarten Development <i>Edita SLUNJSKI</i>	685
Parental Attitudes as Predictors of Subjective Well-being of Psychological Counseling and Guidance Department Students* <i>Hatice KUMCAGIZ</i>	690
Peer Learning in HE: Students' Perceptions of the Benefits and Challenges in Becoming Peer Leaders in a Peer Assisted Learning Programme <i>Annyza TUMAR</i>	697
Peculiarities of the Information Structure of Written Discourse and its Use in Flt Classroom <i>Golovchun A.A., Zolotukhina YE.</i>	705
Peripheral Studies of Muslim Identity in Islamic World: Malay Muslim Case Study <i>Muhammad Hilmi JALIL, Jawiah DAKIR, Noor Aziah MOHD AWAL, Fariza MD SHAM, A'dawiyah ISMAIL, Wan Zulkifli WAN HASSAN, Siti Maheran ISMAIL@IBRAHIM, Mohd Irfan MOHD TERIN</i>	711
Physical Activities and Special Education. A Case-Study With Autism Spectrum Disorders Students <i>Laura Sara AGRATI, Francesco FISCHETTI</i>	716
Policy Analysis on the Use of an E-learning Platform at a Higher Education Institution <i>Ain Nurhazifah JASMEI, Cassandra Siaw Yung CHIN, Joanna Suk Shin LIM, Pei Fun LEE, Norain Awang Damit @ HARUN, Azaharaini MD JAMIL, Masairol MASRI, Masitah SHAHRILL</i>	722
Positive Discipline and Behavior Approach For Addressing Negative Behaviors in Education: Model of Ari Schools <i>Seva DEMİRÖZ</i>	733
Positive Psychology and School Intervention – What School Psychologist Could/ Should do	737

Jana VERNARCOVÁ

Preferred Value Structure By Adolescent Girls And Boys <i>Anežka HAMRANOVÁ, Blandina ŠRAMOVÁ</i>	743
Preschool Teacher Candidates' Metaphoric Perceptions About The Concept of Music <i>Aylin MENTİŞ KÖKSOY</i>	749
Presumptions for "International Trade" Studies – Comparison the Czech and Slovak Education System Effectiveness <i>Milos MARYSKA, Petr DOUCEK</i>	755
Primary School Students' Metaphors About the Concept of Mathematics <i>Nihan SAHINKAYA, Çiğdem KILIÇ</i>	763
Project Teaching at University - A Tool for Presenting Proposals for Prevention and Solving the Problem of the General Public <i>Martina JUŘÍKOVÁ, Josef KOCOUREK, Eva GARTNEROVÁ</i>	768
Promoting Academic Integrity in Secondary Education <i>Bagus Hary PRAKOSO</i>	775
Promoting Students Metalanguage Awareness Through Genre Pedagogy <i>Murti Ayu WIJAYANTI, Wawan GUNAWAN, Emi EMILIA</i>	784
Prospective Teachers' Metaphors on Scientific Literacy and The Nature of Science <i>Ijlal OCAK</i>	789
Protection and Promotion of Mental Health <i>Jarmila KRISTOVÁ, Zuzana BACHRATÁ, Emilia MIKLOVIČOVÁ</i>	798
Reasoning and Moral Judgement in Higher Education Students: Reality and Challenge <i>Madalena CUNHA, João DURTE, Ernestina SILVA, Daniel SILVA, João PINA</i>	812
Reconciling the Terrible Twins: Investigating the Relationship of Literacy and Numeracy in Primary Classrooms <i>Maura SELLARS</i>	825
Refining Inconstancy Of Prayer Among University Students By Using Digital Visual Schedule <i>Amin Mohd DAMANHURI, Muhammad FAZRULILAH, Siti Humaira RAMLI, Muhamad Fairus KAMARUZAMAN</i>	829
Reflections on People' s Needs in Bangkok Community Based on Lifelong Learning Concept <i>Sumolnit KERDNOONWONG</i>	838
Religious Education in North Cyprus <i>Ali DAYIOĞLU</i>	843
Repositioning Technical Education a Panacea to Solving Globalization Challenges in Construction Sector <i>Lekan AMUSAN, Dele OWOLABI, Patience TUNJI-OLAYENI, Raphael OJELABI, Ignatious OMUH, Ayodeji OGUNDE, Opeyemi JOSHUA</i>	849
Role of Tablet Technology Towards Children with Autism Learning Development: A Study on the Acceptance of Special Education Teachers <i>Muhamad Fairus KAMARUZAMAN, Harrinni Md NOOR, Mustaffa Halabi Haji AZAHARI</i>	856
Roma in the Czech and Slovak Republic in the Spectrum of National Diversity <i>Jaroslav BALVÍN</i>	865
Satisfaction Level of Faculty of Education Students with the Service Quality of Teaching	877

H.Ömer BEYDOĞAN

Scale Development and Validation for Career Aptitude Test for Designers in South Korea <i>Imjoo GIL, Daedong HAHN</i>	890
Scale of Social Values in Turkish Folklore <i>Azmiye Yinal, Nuran Soytekin, Habib Derzinevesi</i>	902
School Image Based on Its Value Messages <i>Eva POLIAKOVÁ, Anežka HAMRANOVÁ, Blandina ŠRAMOVÁ</i>	910
Schools as Institutes of Acculturation: A Question of Belonging <i>Maura SELLARS</i>	917
School-Work Alternating In Italy: A Critical Study <i>Francesca SARTORI, Carlo BUZZI</i>	921
Self-Correcting Mechanism in Education: A Mechanism to Improve Reading a Language Taken Online <i>Nabil Al-AWAWDEH</i>	927
Self-Efficacy Study of Computer Science Engineering Students <i>Ildikó HOLIK</i>	930
Semantic Translation of Selected Pun Words From the Holy Quran into English <i>Mohammed H. Al Aqad, Kulwindr Kaur, Ahmad Arifin Bin Sapar, Kais Amir Kadhim, Nor Hazrul Mohd Salleh</i>	936
Semi-Unplugged Tools for Building Algorithms With Sprego <i>Piroska BIRO, Mária CSERNOCH</i>	946
Shooting Short Film as an Application of Values Education <i>Mustafa SOZEN</i>	958
Skill Versus Content: Using Twitter in the Literature Classroom <i>Zainor Izat ZAINAL, Ann Rosnida Mohd DENI</i>	964
Social Competence, Hope for the Success and Participation in Popular Culture of Polish Students of Education and Special Education <i>Kamil KURACKI</i>	972
Social Innovation in Small Schools in Thailand <i>Thanakorn SRIWIPHAT, Dawruwan THAWINKARN</i>	978
South Korean University Students' Views of Mobile-Assisted Language Learning <i>Andrea Rakushin LEE</i>	984
Sound Creation and Artistic Language Hybridization Through the Use of the Collaborative Creation System: Soundcool <i>Noemy BERBEL-GÓMEZ, Adolf MURILLO-RIBES, Jorge SASTRE-MARTÍNEZ, María Elena RIAÑO-GALÁN</i>	997
Status and Improvement of Human Rights Education for Police in Korea <i>Chong, SANGWOO, Kang, EUNYEONG, Han, HWAERYEON</i>	1010
Students' Game Playing Preferences And Personality Traits <i>Simon SO</i>	1014
Study About the Perception of Basic Digital Competences of Students of a Chilean University <i>Lagunes Domínguez AGUSTIN, Judikis Preller Juan CARLOS, Torres Gastelú Carlos ARTURO, Flores García María ALICIA</i>	1023

Study Collocations Through Language Corpuses <i>Leila Yu. MIRZOYEVA, Khafiza A. ORDABEKOVA</i>	1030
Study on Continuous Training for University Teachers: Analysis of Training Programmes <i>Josué ARTILES-RODRÍGUEZ, Josefa RODRÍGUEZ-PULIDO, Arminda ALAMO-BOLAÑOS, Victoria AGUIAR-PERERA</i>	1036
System Architecture of Business Intelligence to Aun-Qa Framework for Higher Education Institution <i>Thada JANTAKOON, Panita WANNAPIROON</i>	1045
System of Continuous Professional Development for Language Teachers in Kazakhstan: Issues and Perspectives <i>Oxana SYURMEN, Maira ZHOLSHAYEVA</i>	1053
Systemic Approach in "Mother-Child Home" Projection in Education <i>Leyla SURI</i>	1058