Is it Better to Learn from Problems or Erroneous Examples?

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***Abstract*—Unified Modeling Language (UML) is a modeling standard that has been commonly used in the software industry. However, students face difficulties while learning how to model complete and correct UML diagrams. One of the reasons is the way UML has been taught. In order to improve the effectiveness of learning it is necessary to employ methods in which the students actively take part in the learning process. This paper describes an empirical study that evaluates two teaching methods: Problem Based Learning (PBL) and Learning from Erroneous Examples (ErrEx). We compared these methods by assessing the degree of correctness and completeness of the produced diagrams. We analyzed students' perceptions about each method. The quantitative results showed that the diagrams created using both methods presented similar level of correctness and completeness. The qualitative results showed that students found PBL easier when learning UML diagrams. Results showed that students found PBL easier when learning UML diagrams.**

Keywords—UML Teaching; Modeling Education; Problem Based Learning; Learning from Erroneous Examples; Empirical Study;

I. INTRODUCTION

The capacity to abstract has become one of the most important skills in Software Engineering (SE) [1, 2], since it enables an in-depth understanding of a specific concept or a problem using different levels of detailing [1, 3]. From abstract thinking, students and professionals are able to analyze and design models used during software development [1, 2].

Unified Modeling Language (UML) [4] has been adopted as a standard modeling language in the software industry for the graphical representation of analysis and design models [5, 6]. Learning how to model UML diagrams has become a necessity for SE students and professionals [7]. However, during the learning process, students have presented difficulties while creating these diagrams, such as: difficulty in understanding the diagram's syntax and semantics, difficulty in organizing information on the diagrams, difficulty in correctly using association of the type generalization-specialization, among others [7, 8, 9, 10]. These difficulties can affect the final software quality, since these diagrams would incompletely and incorrectly represent the software [7, 8, 9].

One of the reasons for these difficulties can be the way the UML has been taught [8], once the traditional teacher-centered approach is still dominant in Computer Science [11]. According to Al-Tahat [10] and Chen et al. [11], the challenges associated with this teaching approach are (a) the lack of in-class active learning, and (b) the students are passive learners. The SE curriculum is not an exception.

Therefore, it is necessary to explore new pedagogical methods, which provide students with a challenging environment, in a way that the students are actively involved in the learning process [12]. A promising area in Computer Science is Active Learning (AL) [13, 14]. According to Freitas et al. [12], in the AL approach, students are immersed in a learning environment in which learning domains (knowledge, skills and attitudes) are stimulated. AL promotes students' involvement, improves academic performance, as well as students' attitudes. In addition, AL offers to students a natural environment for improving their interpersonal skills and developing problem solving and life-long learning skills [14]. Among the methods implemented with AL, we can include Problem-Based Learning (PBL) [15] and Example Based Learning (EBL) [16, 17].

PBL is a pedagogical method that emphasizes on the role of a problem, in which the students are responsible for their learning [15]. This method helps the students developing strategies and constructing knowledge. Team formation and role distribution are essential for the use of PBL [18]. Example Based Learning is another method based on AL. EBL engages the students in an AL exercise [16, 17], offering the opportunity for a constructive and collaborative learning experience through examples [19, 20]. One of the strands of EBL is Learning from Erroneous Examples (ErrEx) [21, 22]. In ErrEx, students attempt to solve a problem in which one or more examples are incorrect. This method helps mainly in initial skill acquisition in the learning process [19, 22, 23]. Moreover, McLaren et al. [22] state that ErrEx helps the students to (a) more carefully study the examples, and (b) to remember and avoid errors found and learned in a future activity.

Aiming to understand the influence of PBL and ErrEx methods in the process of learning UML diagrams, this paper describes an empirical study conducted with 44 undergraduate students of the Federal University of Amazonas (UFAM). The study was carried out while the students were learning two UML diagrams: Activity and Sequence Diagrams. We chose these diagrams because they help in understanding the dynamic behavior of the software [4] by representing: system's control

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and data flows (Activity Diagram); and the temporal interaction among objects (Sequence Diagram).

In this study, we compared PBL and ErrEx methods because they [14, 15, 16, 17, 19, 22]: (a) provide context for subsequent retrieval and appropriate use of new information to students; (b) are effective learning methods; and (c) the students actively take part in the learning process. These methods were evaluated in by assessing the diagram's correctness and completeness, as well as the students' perception about each method. By measuring these indicators, we expected to understand how these methods assist students in the modeling of correct and complete diagrams. In addition, students provided feedback about their perceived learning about the methods. After the quantitative analysis, we carried out a specific analysis of the qualitative data obtained from the students' comments about each method. To analyze the qualitative data, we used open coding and axial coding procedures from Grounded Theory (GT) [24], to extract the benefits and difficulties perceived by the students after using the methods.

The remainder of this paper is organized as follows: Section II presents the background about the learning methods. Section III describes the empirical study. Section IV discusses the results of the quantitative and qualitative analysis, respectively. Section V presents some discussions. Section VI describes the threats to validity. Finally, Section VII presents the final considerations and future works.

II. BACKGROUND

This section presents the main concepts related to the teaching methods which will be used in this paper: Problem Based Learning and Example Based Learning.

A. *Problem Based Learning*

Problem-based Learning is a method used to structure the learning activities [15]. In PBL, the problem is the key point which initiates the learning, while the students work in small collaborative groups to resolve them [15, 18]. In this method, the students assume the responsibility of defining their own learning objectives and new information is expected through their investigation to a solution to the problem [18]. PBL offers the students a way of acquiring knowledge and developing their skills and attitudes expected as a professional [25].

There are specific ways of implementing PBL. We adopted the method from the medical school of University of Helsinki, where PBL was based on the seven steps method developed by Maastricht University [26]. The steps are: (1) clarifying concepts; (2) defining the problem; (3) analyzing the problem/brainstorming; (4) categorizing ideas; (5) formulating learning objectives; (6) self-study; and (7) discussion of newly acquired knowledge. In steps 1 and 2, the team becomes familiarized with the case material and identified the problem, respectively. In 3, the group discusses the ideas and perceptions about the problem in order to activate other knowledge which could be helpful in the solving of the problem. After brainstorming, the knowledge is structured and systematized (step 4). This way, the group tries to create a sketch that explains what happens in the case. In addition, the group tries to understand what is essential for creating a solution, leading to the definition of learning objectives (step 5). In step 6, each student studies independently in order to achieve all his / her learning objectives. Furthermore, the student's responsibility is emphasized for the acquisition of knowledge. Finally, in 7, the group discusses the case and tries to resolve it, based on the knowledge obtained.

Regarding the use of PBL in the teaching of Computer Science, Oliveira et al. [27] carried out a systematic literature review and identified evidences showing that most of the applications of PBL are centered around their applicability in Software Engineering courses. Furthermore, PBL can help in teaching modeling and in supporting the students to model diagrams correctly and completely [28]. Therefore, the students are able to develop systems in a more logical way, and with fewer defects. Based on the characteristics presented, it is relevant to investigate how PBL helps in teaching UML diagrams.

B. *Example Based Learning*

Example Based Learning is an efficient and effective instruction strategy for teaching students new problem-solving skills [19, 20, 29]. Human beings learn with examples, generalizing information and constructing mental models [20]. It is easier to abstract and solve problems in a more effective way if the new material is presented with multiple examples [19]. The use of examples reduces the mental effort necessary to understand problems [30]. Therefore, teaching using examples makes learning more effective and as efficient [29]. Examples are commonly used in Software Engineering. Zayan et al. [30] cite various approaches that postulate examples that must be used to specify software behavior. For instance, test cases are examples of what the software must do. In this sense, the importance of employing examples in software modeling seems to be underestimated [31].

Another way of teaching software modeling is to present the students with erroneous examples (Learning from Erroneous Examples – ErrEx) and instruct the students to encounter, explain and fix the errors [21, 22, 23]. This would not only cause the students to carefully study the examples, but also help the students to remember and avoid repeating them in the future. Learning from errors can foster the acquisition of "negative knowledge," which provides important protection against erroneous decisions [22, 23]. Thus, the students can clearly understand what is wrong and why something is wrong in a given situation.

Große e Renkl [21, 32] carried out two studies comparing the effectiveness of correct and incorrect examples. The authors showed that students obtained better results with incorrect examples. Given this basis, it is important to verify whether the use of erroneous examples offers significant benefits in the modeling of UML diagrams.

III. EMPIRICAL STUDY

We conducted an empirical study to evaluate the effects of the use of PBL and ErrEx methods in learning how to model UML diagrams, more specifically, activity and sequence diagrams. In this study, we compare these methods in terms of degree of correctness and completeness of the diagrams created during the course. In addition, we analyze students' perception about the learning methods. By understanding these perceptions, we believe that we can comprehend the factors that prevent and/or help the student to achieve the educational goals when employing PBL and ErrEx methods.

A. Context of the Course

This study was performed with 44 undergraduate computer science major students of UFAM in Brazil. We chose to work with these students because they are the future software engineers. We believe that, by applying the appropriated methods during their learning process, the industry can benefit of better professionals. These students were attending to the Software Analysis and Design course, which focuses in: (a) presenting the fundamentals of software modeling, as well as the concepts of object-oriented analysis and design; (b) practicing the concepts using UML. Therefore, the contents of the course are split into three parts: (1) fundamentals of analysis and process, and software development process management; (2) process for the identification of software components and artifacts based on the specification model; and (3) modeling of business process, components, architecture, and software product line.

B. Study design

The activities that make up the process for carrying out of study are described in the following subsections.

1) Planning of study – In this step, preparation of the materials used in the study was carried out: elaboration of the consent-free form, scenarios definition, study instructions, and post-modeling and post-study questionnaires. All the study artifacts were discussed with and validated by two other researchers.

2) Execution of study – Initially, the students were split into groups based on convenience, in which they decided which students would be part of their groups. The activities were carried out in groups to promote engagement among students, as well as active collaboration. Altogether, nine groups were formed (eight groups of five students and one group of four students) (Table I). Next, all the enrolled students (44) signed the consent form, granting us access to the data created during the assignment. We highlight that students had no prior experience in modeling. Fig. 1 shows the procedure followed in the study. Before each session, the students attended to a theoretical class about the diagrams they would model. The class focused on the fundamentals which would be necessary for the students to understand the diagrams' objectives and notation. Moreover, we administered exercises to verify the students' understanding about the presented topics. Each session lasted two classes (1h40 per class). In the first session, the students were requested to model the activity diagram, and, in the second session, the sequence diagram. On the first day of the study, the groups received training about how the PBL method should be used. After that, each group received a scenario with a problem, and were asked to model the activity diagram employing PBL method. At the end of the modeling, the students answered a questionnaire aiming at verifying their perceptions of PBL. On the second day, the same procedure was performed: (a) training the students on how to apply the ErrEx method; (b) providing the students with a scenario with a problem and an activity diagram with syntactic and semantic defects, and were asked to model a new activity diagram; and (c) administering a questionnaire about the students' perceptions about ErrEx. In the second session, the methods were inverted and used to model sequence diagrams. In this case, the students first used ErrEx method to aid in the modeling of the sequence diagram and, next, used PBL method.

TABLE I. DISTRIBUTION OF STUDENTS PER GROUP.

G	Students	G	Students
G1	S19; S20; S23; S39; S41;	**G6**	S01; S37; S29; S21; S02
G2	S26; S32; S33; S35; S36;	**G7**	S40; S04; S07; S05;
G3	S12; S16; S30; S38; S42;	**G8**	S14; S06; S22; S03; S09;
G4	S34; S11; S08; S10. S24;	**G9**	S17; S13; S43; S18; S44;
G5	S28; S27; S15; S25; S31;	**Note**: **G** – Groups.	

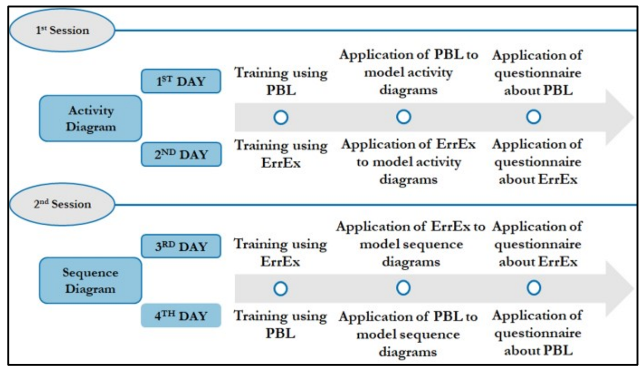

Fig. 1. Procedure followed in the study.

3) Analysis of Results – Finally, we analyzed our results. In this step, the researchers analyzed the diagrams and the answers to the questionnaires. For the diagram analysis, we employed objective metrics related to the quality of the diagrams: (a) correctness and (b) completeness. According to Granda et al. [33], correctness defines how much a diagram employs the elements and relationships, according to the syntax of the notation. The correctness is affected by following types of defects: inconsistency, extraneous information, incorrect fact, and ambiguity. Completeness defines how much a diagram presents necessary information according to the purpose of modeling. This metric is related to the diagram's semantics, in which information omission reduces the completeness. Table II shows the formulas used to calculate the metrics. The diagrams' evaluation was performed by a researcher and revised and discussed by two other researchers.

TABLE II. FORMULA EMPLOYED FOR METRICS.

Formula
Correctness = TP / (TP + FP)
TP: True Positive (number of elements correctly modeled in the diagrams). **FP:** False Positive (number of elements incorrectly modeled in the diagrams).
Completeness= RI / (RI + MI)
RI: Relevant Information (amount of necessary and relevant information for the diagram). **MI:** Missing Information (amount of necessary information that is not in the diagram).

IV. Results of the Study

This section presents the quantitative and qualitative results obtained in the empirical study.

A. *Results of Correctness and Completeness Analysis of the Elaborated Diagrams*

Table III shows the overall correctness and completeness of the diagrams modeled while using PBL and ErrEx. The diagrams' completeness and correctness range from 0.0 (worst possible result) to 1.0 (best possible result).

TABLE III. Summary of the Quantitative Results by Group.

G	PBL				ErrEx			
	Correctness		*Completeness*		*Correctness*		*Completeness*	
	AD	SD	AD	SD	AD	SD	AD	SD
G1	1.00	0.97	0.95	0.84	0.87	1.00	1.00	0.30
G2	1.00	1.00	0.86	0.95	0.96	0.97	1.00	0.83
G3	0.87	1.00	0.88	0.80	0.96	0.71	0.93	0.73
G4	0.84	0.97	0.93	0.87	0.95	0.94	0.91	0.81
G5	0.98	1.00	0.96	0.90	0.96	0.98	1.00	0.90
G6	0.80	1.00	0.98	0.87	0.86	1.00	0.90	0.83
G7	0.84	0.73	0.87	0.86	0.88	--	1.00	--
G8	0.97	1.00	0.82	0.58	0.88	0.93	1.00	0.50
G9	0.98	1.00	0.77	0.30	--	0.80	--	0.60
M	0.92	0.96	0.89	0.77	0.91	0.90	0.96	0.69
Md.	0.97	1.00	0.88	0.86	0.91	0.90	1.00	0.77
SD	0.08	0.08	0.07	0.20	0.05	0.05	0.05	0.20

Note: **G** – Groups; **AD** –Activity Diagram; **SD** –Sequence Diagram; **M** – Mean; **Md.** – Median; **SD** – Standard Deviation;

During the application of the ErrEx method, groups G7 and G8 did not show up, and, because of this, they are marked as "--" in the TABLE III. We used the boxplots to facilitate the data visualization (Fig. 2 and Fig. 3).

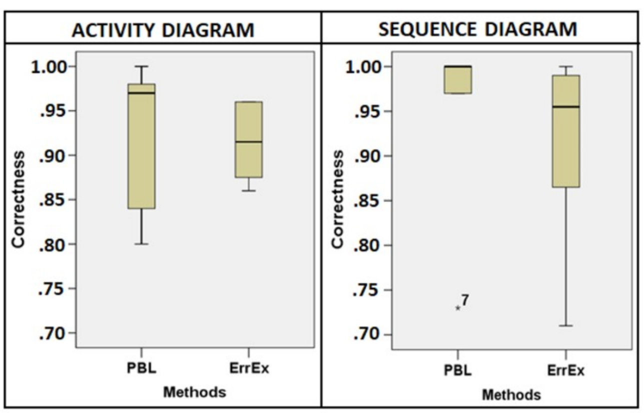

Fig. 2. Boxplot for Correctness.

Regarding activity diagram correctness, as shown in Fig. 2, we can observe that the median score for both PBL and ErrEx methods is above 0.90. One can notice that correctness of the activity diagrams for both methods is dispersed, however all scores are above 0.80. This dispersion could have been caused by difficulties in correctly representing the notation of the activity diagram. For example, one of the most identified defects was the incorrect or non-representation of the synchronization bar on the diagram. With respect to correctness of the sequence diagrams modeled while using PBL, although group G7 obtained a low value, the scores for correctness are very high and close to the median. On the other hand, the correctness of the sequence diagrams created using ErrEx method showed very dispersed scores. Some students also have difficulties in correctly representing the sequence diagram. For instance, the students did not know how to represent that the interaction among the objects is realized using a controller. However, by using the PBL method, the students were able to model more correct sequence diagrams.

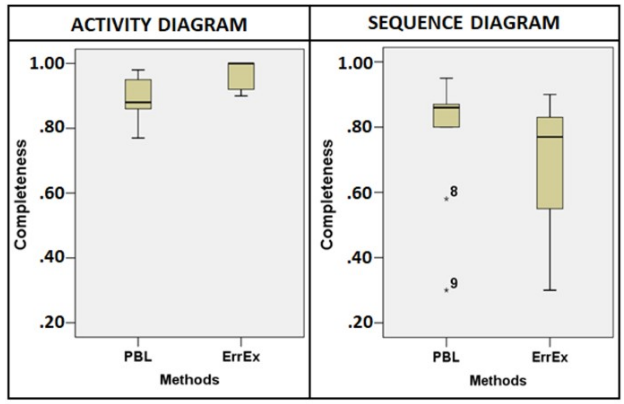

Fig. 3. Boxplot for Completeness.

In the Fig. 3, we observe that the median score for the activity diagrams' completeness using PBL was 0.88, while using ErrEx it was 1.00. Moreover, the completeness scores for the diagrams modeled using ErrEx are close to the median, differently from the distribution observed for PBL. Thus, we have indication that, by employing ErrEx, the students were able to model more complete activity diagrams. Regarding the completeness of sequence diagrams created while employing the PBL method, two groups obtained results very below the median (G8 and G9). However, the results for this method are well concentrated around the median (0.86). The completeness of sequence diagram using the ErrEx method is very dispersed. In this case, the completeness varies between 0.30 (minimum) and 0.90 (maximum).

B. *Students' perception about methods.*

In order to carry out a comparative analysis of the methods, the students also answered four questions (see Table IV).

TABLE IV. Students' Perception about methods.

Objective	Question
Easiest method	Which are the teaching methods you considered easiest to learn to model diagrams?
Most difficult method	Which of the teaching methods did you consider most difficult to learn to model diagrams?
Preference	Among the methods used to teach diagrams, which of them do you prefer?
Engagement Level	Classify your level of engagement after using each of the methods (Traditional Method, PLB and ErrEx).

Fig. 4 shows that the students considered the PBL method easier to learn and model (18 students), followed by the Traditional Method (TM) (13 students) and then by ErrEx (6 students).

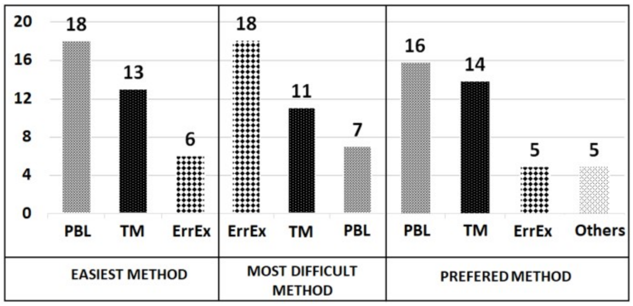

Fig. 4. Result of Students' Perception about methods.

The students commented that PBL was easier because it stimulates more in-depth thinking about the problem, and allows students to be familiar with real world problems, as shown in the quotes below:

"The method stimulates thinking (...) and allows for completeness of the theory." – S17

"I had more facility in creating alternatives to the solutions of the problems using PBL." – S01

According to Fig. 4, the ErrEx method was considered the most difficult for learning and modeling (18 students), followed by the Traditional Method (11 students) and then by PBL (7 students). The ErrEx method might have been considered the most difficult due to two factors: (a) the addition of more than one step during the teaching process; and (b) the difficulty in identifying errors in the diagrams, as shown by the following quotes:

"*ErrEx adds one more step [the search for errors], which breaks down the reasoning that we constructed after reading the specification."* – S32

"*The ErrEx method did not provide much contribution, just like the other methods, because we had difficulties in finding errors*." – S33

With respect to method preference to learn how to model (Fig. 4), the results showed that the students preferred PBL (16 students), followed by the Traditional Method (14 students), then ErrEx (5 students), and Other Methods (5 students). Regarding the preference for PBL, the students mentioned that the method promotes more concrete learning, as shown in the following quotes:

"I believe that PBL offers more concrete learning by applying and discussing concepts." – S32

The TM was the second method chosen by the students. This was due the students felt more secured when the professor was explaining the content (see quotes below):

"*With the professor's guidance, it is easier to avoid errors and clarify doubts."* – S07

"I feel more motivated to learn and try to correctly apply the concepts thought." – S29

ErrEx method was the third preferred method by the students. Despite this, the students state that ErrEx is practical and it is possible to learn what you cannot do while modeling, as shown below:

"*I consider ErrEx the fastest to learn what not to do.*" – S08

Some students preferred to learn to model using "Other Methods" (5 students). Two students did not inform the name of the methods, one student mentioned that he prefers '*Video courses/online learning, with some practical classes in case of any doubts*' (S02), other students informed that they preferred to learn by themselves (self-learning). One student reported that he prefers a combination of the three methods (TM, PBL and ErrEx). Some students reported that the *three methods were important in learning modeling* and that it could be done by a combination of TM with PBL and ErrEx. According to the students, this combination helps in obtaining different visions of the same problem, as can be seen below:

"the three are necessary, PBL and ErrEx combined with the traditional (method) would be better." – S20

"*I prefer a method that can cover all the methods, in order for us to have diverse visions about the same problem."* – S23

"*It is obviously very important to have the traditional method. A lot of PBL and some of ErrEx to help detect possible errors."* – S22

C. Students' perceptions about PBL and ErrEx methods.

We applied post-modeling questionnaires aiming to evaluate the perceived learning by the students regarding to the use of PBL and ErrEx methods. The students provided their answers in a 5-point Likert Scale, with alternatives ranging from "I Strongly Disagree" (-2) to "I Strongly Agree" (2). The questionnaire items, presented in Table V, were based on the dimensions of learning [34, 35]. Items 01 and 02 aimed at evaluating if the methods contributed to the learning of the course and items 03 to 08 were elaborated according to the learning levels of Bloom's Taxonomy [36].

TABLE V. ITEMS EVALUATED IN POST-MODEL QUESTIONNAIRES

Item	Description of Item
Item 01	The PBL/ ErrEx method contributed to my learning of the course.
Item 02	The PBL/ ErrEx method was efficient for my learning, in comparison with other activities of the course.
Item 03	The PBL/ ErrEx method helped in remembering the concepts learned about the diagram.
Item 04	The PBL/ ErrEx method contributed to interpret how the concepts learned can be useful in the modeling of the diagram.
Item 05	The PBL/ ErrEx method contributed in applying the concepts of the diagram during the resolution of problems.
Item 06	The PBL/ ErrEx method contributed to organize the diagram during the modeling.
Item 07	The PBL/ ErrEx method contributed to verify if the diagram was correctly modeled.
Item 08	The PBL/ ErrEx method contributed to create the diagram during modeling.

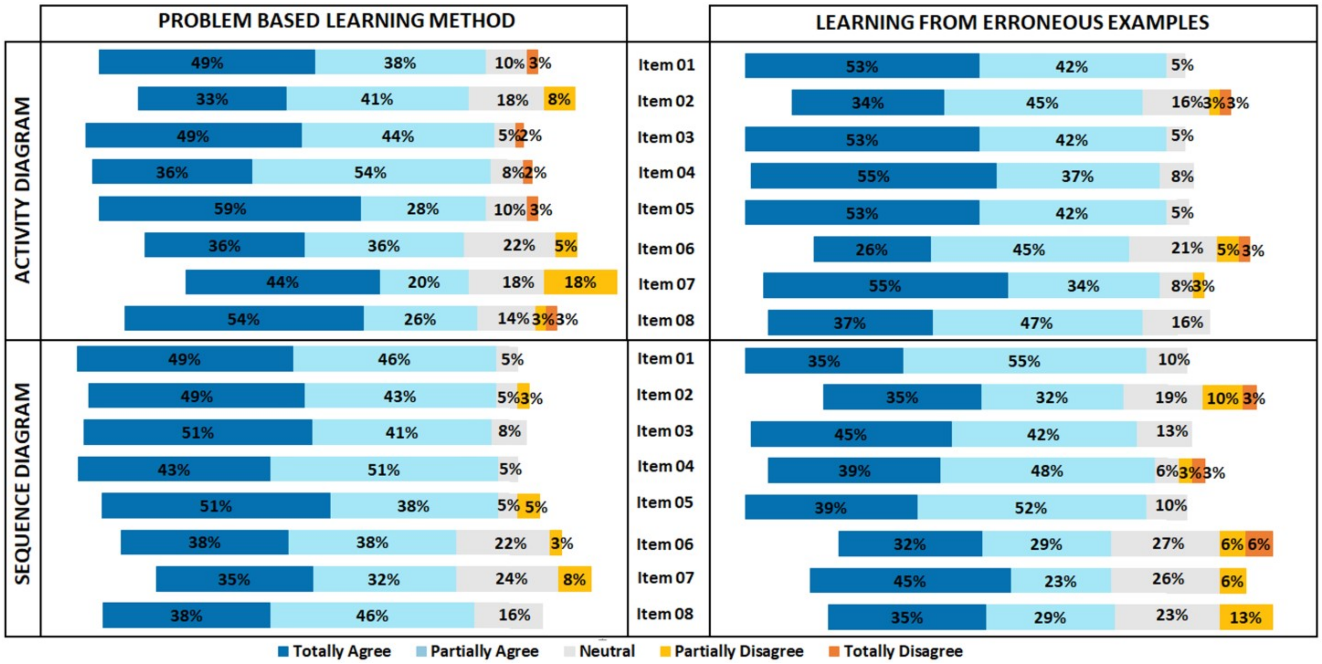

Fig. 5. Students' perception of the PBL and ErrEx method.

Fig. 5 presents the students' perceptions with respect to the learning of the activity and sequence diagrams using PBL and ErrEx methods.

Regarding the activity diagram learning, most of the students agreed that the methods positively contributed to learning. For the item that evaluates if the method contributed to learning (item 01), a good agreement level was obtained relative to both methods (87% agreement for PBL and 95% agreement for ErrEx). For the item that evaluates whether the method helps in correctly modeling a diagram (item 07), the lowest agreement level was obtained for PBL (64% agreement). Furthermore, with respect to PBL, this item obtained the highest discordance level (18% discordance). This discordance can be related to the fact that the method must have been used only aiming to create diagrams. However, the students' general perception of using both methods to learn activity diagrams was classified as very positive. This shows that the use of PBL and ErrEx promoted a good perception for the students, especially in terms of remembering, interpreting and applying concepts.

With respect to sequence diagram, learning using PBL and ErrEx methods, item 01 (contribution to learning) was the best evaluated by the students. According to the students' perception, both methods contributed to the learning of diagrams in the course. In item 02 (method efficiency), we perceived a high agreement level for the PBL method (92%). However, there was a 67% agreement level from the students about the use of ErrEx. Also, regarding ErrEx method in this item, students were noted disagreeing (13%) or being neutral (19%). In item 08 (creating a diagram), 84% of the students considered PBL helpful in creating diagrams, while 64% of them agreed to this item for the ErrEx. Still in this item, with respect to the ErrEx method, it was perceived that there was a high discordance level (13%) as well as neutral responses (23%). According to students' perception in relation to learning the sequence diagram, it can be noted that, for the ErrEx method compared to PBL, a large number of participants disagreed or remained neutral with respect to the items evaluated. This shows that the PBL method stood out to be more efficient in the creation of diagrams, aiding in the learning of sequence diagrams.

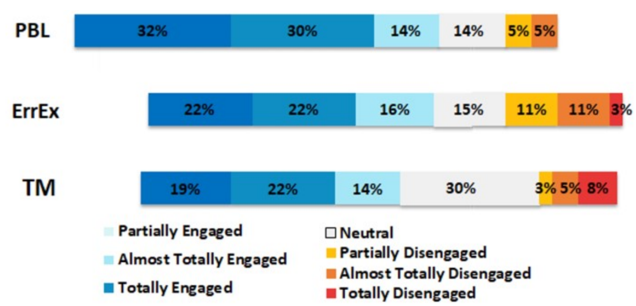

Fig. 6. Level of student engagement regarding methods.

Regarding students' engagement level according to the methods, in Fig. 6, we observed that the students felt more encouraged using PBL (76% agreement). Furthermore, the smallest discordance level was related to this method (10%). Regarding ErrEx and TM methods, the students agreed that they help in engagement, respectively 60% and 55% agreeing. Although there were few students who disagreed, there was more discordance regarding ErrEx method (25%).

D. Qualitative Results

After the quantitative result analysis of the questionnaires, we carried out a specific analysis of the qualitative data (additional comments). The qualitative analysis was based on open coding and axial coding procedures from Grounded Theory [24]. Although the purpose of the GT method is the construction of substantive theories, the researcher may use only some of its procedures to meet one's research goals [24]. We decided not to perform the selective coding because the open and axial codification phases were enough to understand students' perceptions about PBL and ErrEx methods.

The objective of the qualitative analysis was to identify the difficulties and benefits perceived by the students after using the methods (PBL and ErrEx). By analyzing the participants' additional comments, we created codes (relevant concepts for the understanding the perception about the methods) related to the answers of the students (participants' quotes) (open codification). After this, the codes were analyzed and grouped according to their properties, forming concepts that represent categories and subcategories. Next, codes were related to each other (axial coding). The analysis was conducted by one researcher, and reviewed by other two, more experienced, researchers. This was performed in order to mitigate the eventual bias caused by the participation of just one researcher in the codification process. The following subsections will present more details about the results identified in the qualitative analysis.

1) Students' perception in relation to the PBL method. From the qualitative data analysis, we identified three main categories: (1) PBL helped in the learning of diagrams; (2) group discussion using PBL improved the learning of diagrams; and (3) PBL did not help in learning during modeling.

The category **PBL helped in the learning of diagrams** is composed of three subcategories. First, PBL stimulated the understanding of concepts learned about diagrams, the student S01 commented that "*certainly PBL helped to remember and apply the concepts learned about the diagram.*" Moreover, S07 highlighted that with the use of PBL "*the concepts that were not well understood by some members were remembered and applied by others who had understood.*"

Other students stated that PBL helped in modeling the problem in a practical way. The student S07 commented that the "*problem helped in having a better idea of how the systems functions in practice, and, this way, helped in modeling diagrams.*" S27 added, saying that "*the presentation of a real scenario instigates the exploration of concepts and possibilities to solve problems.*"

Furthermore, PBL helped in showing the relationship among the diagrams. We could observe that the students succeeded to understand the relationship dependence among the diagrams. Given this, S19 said "*I succeeded to see the connection existing between the class diagram and the sequence diagram and therefore made the creation of the sequence diagram easier.*" Therefore, PBL help students understanding the importance of a diagram for modeling another.

The category **group discussion using PBL helped in learning of diagrams**, brings some benefits of discussing in groups using PBL to learn how to model diagrams. We evidenced that PBL improved the interaction among the team members. To illustrate this subcategory, S40 mentioned "*the method helped in improving learning by greatly stimulating contact with other people, as well as stimulating dialogue, facilitating information retrieval from the problem.*" In addition, S41 commented "*group debating helped in responding to 'useless questions' which at times, students feel awkward asking in class.*" This shows that PBL allows the students to attain collective learning.

Another benefit is that PBL enabled students to obtain different perspectives about the problem. The student S37 confirmed that from the "*interaction with other colleagues, it was possible to verify other viewpoints about the same problem and different ways of elaborating solutions."* The student S04 also highlighted that with this interaction "*each member [of the team] gave his opinion, hence helping us to arrive at a better conclusion of the problem.*"

Finally, PBL helped in correctly modeling a diagram. S01 said that "*group discussion was fundamental for the creation of correct and complete diagrams.*" Moreover, according to S33, PBL "*made discussion among members flow which helped in correctly creating the diagrams.*"

The codes related to the above categories showed evidence that the students had a good perception of PBL. However, the students, who emphasized that **PBL did not help in learning during modeling**, also identified some difficulties. One of the difficulties perceived by the students is that team size negatively influenced the modeling. To this respect, the student S14 stated that "*due to the large group size (5 people), there were a lot of divergent opinions that made modeling a little difficult.*" The student S14 reported "*a smaller group size would make it easier to model.*"

Another difficulty is related to different visions of team members made modeling difficult. According to student S26, during modeling "*it was difficult to reconcile the different visions and abstractions of the members.*" The student S22 added that modeling "*took long due to different visions [...] and this made modeling more complicated.*" Furthermore, some students found problems with team interaction. According to S23, the use of PBL "*ended up making the work execution difficult.*" This student also mentioned some of the reasons for these problems: "*contradictory ideas, many people, a lot of confusion in the application of some concepts learned in class.*"

Another difficulty observed concerns to doubts about the correct application of the PBL method. Regarding this difficulty, the student S29 highlighted that "*in a more specific context of the discussion, I believe that we made a few mistakes in the application of the method.*" A hypothesis for the occurrence of this difficulty is that the student did not clearly understand the objective of the activity. In addition, the students felt the need of the professor's orientation, because, according to S10, the group "*lost a lot of time discussing blindly."* S20 commented that this might have occurred because "*in various moments in which I had questions/did not know, my colleagues also did not know or also had questions.*" According to the student, the absence of an instructor to guide him was felt.

2) Students' perception with respect to the ErrEx method. In the analysis, we also identified three categories: (1) ErrEx helped in the learning of diagrams, (2) group discussion using ErrEx improved the learning of diagrams, and (3) ErrEx did not help in learning during modeling.

Regarding the category **ErrEx helped in the learning of diagram**, we identified some subcategories with benefits of using the ErrEx method. According to the participants, ErrEx helped in identifying defects during modeling. With respect to this subcategory, the student S26 commented that the ErrEx method "*showed incorrect examples which were to be corrected and these errors could reappear in a real modeling*". Furthermore, this student stated "*[...] by identifying errors, I was able to learn better.*"

Identifying the error helped avoid them from repeating in future modeling was mentioned by the student S40, who stated that "*haven shown a diagram with defects, it is easier to model ours knowing what not to do.*" Agreeing to this affirmation, the student S28 also reported that "*when we discovered the errors, we learned how not to repeat them in our modeling.*"

Moreover, the ErrEx method helped in understanding the concepts learned. As reported about PBL, the students succeeded to learn the concepts that were though in class using ErrEx. As concerns the benefits of this method, the student S23 stated that the ErrEx method "*is very efficient for me, since the concept and the content were more fixed in my mind.*" Student S23 stated that ErrEx "*allowed me to remember the concepts by applying the correction on the artifact.*"

We perceived that in the ErrEx method, similarly to PBL, the different visions helped in modeling diagrams. The student S29 said that the method "*contributed to the perception of how different visions and different solutions can helped us to better observe the solutions, which were before unperceived.*" As concerns making a diagram available helps in modeling, according to student S31, "*by having a diagram as a starting point, even when it contains errors, it still helps in creating a new one with corrections.*" This shows that despite the errors in the diagrams, it helps in the beginning of modeling.

Also, we noticed that **group discussion using ErrEx improved the learning of diagrams**. We grouped the evidences related to this category into two subcategories. One of the subcategories is ErrEx helped in the interaction between team members. The student S02 mentioned "*discussion with colleagues clarified some doubts and helped in identifying problems which at times we were not able to identify.*" The student S03 complemented, saying that "*debating and seeing group opinion, how its members would do certain things, can improve my understanding of the diagram.*" The second subcategory is ErrEx made all team members to be at the same level of knowledge. To this respect, the student S12 affirmed that "*discussions are always very rich to help us be at the same level of knowledge, given that I consider this part fundamental for aligning, creating sketches and modeling.*" Meanwhile, the student S41 reported that "*since we are a team, this helped to bring us all to the same level of knowledge.*"

Finally, the students perceived some difficulties indicating that the **ErrEx method did not help in learning during modeling**. Students noted that ErrEx did not help to correctly model the diagram. The student pointed out that "*I discovered a new way of incorrectly drawing diagrams, instead of learning how to correctly do it.*" The student S11 said that "*in general, it helped as another means of handling a problem, and even though it did not help in modeling and creation of diagrams, the method helped in verifying if the diagram is correct or not by showing errors, that is, what not to do.*"

The students also reported that, indeed, ErrEx has an error identification step that makes modeling difficult. According to the student S36, "*one loses time looking for errors instead of creating the diagrams.*" Furthermore, S32 reported "*the fact that it first looks for errors and after correct them and then creates another diagram, confuses my thoughts a little.*" The student also said "*I prefer to read the problem and go straight to modeling, without following this additional step in the middle.*"

Moreover, according to the students, ErrEx reduced the interaction among team members, once the students don't start the diagram from the scratch. In this sense, S15 said that having an incomplete diagram reduces the interaction, once "*creating a diagram from scratch causes more discussion among the team.*" As mentioned for PBL, the students commented that teams with a lot of members hindered modeling. According to S14, "*many people hindered the development of the diagram, I recommend 3 people who are randomly selected.*" It is important to note that this difficulty was reported by the same student in both methods, showing that, maybe this student does not like to work in group.

V. Discussion

The qualitative results show that both methods (a) helped in understanding the concepts of diagrams, (b) improved the interaction among the team, and (c) team size make the learning of the diagrams difficult. Regarding *understanding concepts*, with PBL, we noticed that the students succeeded to understand the concepts due to the interaction and discussion that took place among team members during the modeling of the diagram. In the ErrEx method, students were able to understand the concepts because of the erroneous diagram they had. With respect to interaction (b), *both methods helped in improving this factor*. We perceived that the interaction of the PBL method helped the students to discuss their viewpoints about the problem and also in the correct modeling of the diagram. In ErrEx, the interaction made the students to be at the same level of knowledge within the team, which helped in modeling the diagram. Regarding *team size made it difficult to learn the diagrams* (c), one student suggested that the groups could be formed by two or three people, thereby prevent too much discussion from hindering the modeling of the diagram.

We also identified some factors that were considered both positive and negative. In PBL, the factor "*different perspectives of the problem*" can help the participants to discuss, observe and decide the most appropriate viewpoints to perform the modeling of a diagram. However, some participants considered that discussing the different perspectives made modeling a complex and time-consuming activity. Meanwhile, with the ErrEx method, there was divergence about the diagram with defects. Some students reported that the diagram, although wrong, helps in starting to model, and the identification of these defects avoided the repetition of such errors, apart from helping to understand some concepts. However, some participants reported that this step only helps identifying defects, but does not help in modeling the diagram. Furthermore, the students reported that this step reduces the interaction among the team members, because the students started the modeling from the wrong diagram, without directly discussing the scenario.

VI. Threats to Validity

As in all experiments, there are threats that could affect the validity of results. In this section, we discuss the threats to the validity of our findings. We categorized them as per approach as Wöhlin et al. [37] definitions: internal, external, conclusion, and construct threats.

Internal Validity: in our study, we considered four main threats: (1) the use of scenarios to carry out the modeling, (2) participants' fatigue, (3) choice of methods, and (4) order of application of methods. In relation to the first threat, the scenarios could have affected the study in case the students did not understand the scenario. This threat was minimized using scenarios based on real problems. Also, the requirements of this scenario were explicit, such as to simulate some exercises carried out in the classroom. In relation to fatigue (2), this could have influenced the results, due to the fact that the students participated for four days in this study. However, this threat was controlled using scenarios that could be constructed in the stipulated time period. Each session lasted for two classes (duration of 1h40 per class). The choice of methods (3) was done in an impartial way, and the viability of the use of both methods was verified by two researchers. In (4), this could have caused bias due to the order in which the methods were presented. However, all the participants used all of the methods, and the order was inverted in the second session.

External Validity: we considered two threats: (1) validity of the scenarios used, and (2) prior knowledge. In (1), we cannot affirm that the scenarios used during the modeling process represent all the types of scenarios. In (2), all the students had the same level of knowledge in software modeling.

Construct Validity: In this study, the threats considered are the indicators used to measure the correctness and completeness of the diagrams. However, these indicators are commonly adopted in studies that investigate the use of UML models. Therefore, this threat cannot be considered a risk for the validity of results. Furthermore, these indicators were used in other studies to evaluate UML diagrams [33].

Conclusion Validity: the main threat to the conclusion validity was the sample size. The number of participants is not ideal for the statistical viewpoint. However, samples size is a known problem in studies of Software Engineering [37]. Due to this fact, there is a limitation in the results, which should be considered evidences and not conclusive ones.

VII. Conclusion and Future Works

This paper presented an empirical study, which compared two teaching methods in the context of teaching UML diagrams, Problem Based Learning (PBL) and Learning from Erroneous Examples (ErrEx). The quantitative results showed that the median of the correctness of the diagrams (activity and sequence) created using PBL and ErrEx are above 0.90. These results show that adopting PBL and ErrEx methods help the students in satisfactorily modeling the diagrams correctly. Regarding completeness, the median of the results for PBL is above 0.85 and that of ErrEx is above 0.76. However, the quantitative results show that the students modeled more complete activity diagrams by using the ErrEx method (median equal to 1.00), and more complete sequence diagram by using PBL method (median above 0.85).

From the analysis of students' perception of the methods, we could observe that PBL was considered the easiest and the preferred method for learning of diagrams modeling. The reasons for this preference are related to the fact the PBL stimulates the thinking about a problem in a more critical way. ErrEx was considered the most difficult method. One of the reasons is the fact that the method first makes the student identify problems, then carry out the modeling. It is important to note that there were students who preferred this method because it promotes learning in the step for the identification of errors. Regarding the perceived learning, we could observe that, in general, students agreed with the questions related to these perceptions for both methods, that is, the PBL and ErrEx helped in the learning of the activity and sequence diagrams.

The qualitative analysis enabled the identification of benefits and difficulties that influence the learning by employing PBL and ErrEx. The benefits and difficulties that we identified in this study can help the professors in the selection of one of the methods in helping students achieve a specified learning objective. For example, in the case in which the professor wants the students to learn something in a more practical way and that helps them remember some concepts, the method to be adopted is PBL. However, the professor must be present during this process, and adjust the groups so that they don't have interaction problems due to the team size or different visions. In the other hand, if the professor wishes that the students attain their first skills about the understanding of the objective of a specific learning process, ErrEx is the most appropriate method. We highlight that both methods improve the interaction among team members.

Finally, we believe that the creation of an approach that combines PBL and ErrEx with the traditional method must be a point to be discussed. From the results of this study, we perceived that the students justified their choices based on the way that they learned. However, some questions are created: how useful will the combination of the methods be? How much will the students learn if they use the combination of these methods? In this sense, as future work, we intend to carry out new empirical studies: (a) applying the combination of PBL and ErrEx in the teaching of UML diagrams; (b) comparing other teaching methods (for instance, Project Based Learning) to understand how these methods behave in the teaching process of UML diagrams; and (c) identifying factors that can influence the use of these methods.

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