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Can Freshman Science Student Teachers' Alternative Conceptions of 'Electrochemical Cells' Be Fully Diminished?

FETHIYE KARSLI[1] and MUAMMER ÇALIK[2,*]

[1]Department of Science Education, Giresun University, Giresun, Turkey
[2]Department of Primary Teacher Education, Karadeniz Technical University, Trabzon, Turkey

*Corresponding author: E-mail: muammer38@ktu.edu.tr; muammer38@hotmail.com

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The purpose of this study is to investigate effect of 5E learning model incorporating in different conceptual change methods such as computer animations, conceptual change text, worksheet and hands-on activities on remedial program for freshman science student teachers (FSSTs) alternative conceptions of 'electrochemical cells'. The sample of the study consisted of 30 freshman science student teachers (21 girls and 9 boys - aged 18 to 22 years) enrolled in 'general chemistry laboratory' course. An electrochemical-cells concept questionnaire with 6 two-tier questions was employed as pre-, post- and delayed-test. Results showed that the 5E learning model not only helped the freshman science student teachers overcome their alternative conceptions but also store them in long term memory. Needless to say, due to the 5E learning model with different conceptual change methods, some of the freshman science student teachers alternative conceptions have still been robust to be diminished fully.

Key Words: Pre-service teacher education, 5E learning model, Alternative conception, Electrochemical cells.

INTRODUCTION

As a result of constructive learning theory, since 1980s two popular trends have been existed in chemistry/science education literature: (1) determining student conceptions or alternative conceptions (2) use of conceptual change theories to achieve a better conceptual understanding[1]. Term 'alternative conception' means that students hold various conceptions which differ from the scientific one accepted by scientific community[2-4]. In fact, because alternative conceptions are not necessarily spontaneous ideas, they may result from instruction or teachers or the textbooks or the discrepancy between daily language and scientific language or students' social environments[5]. This means that teachers are potentially one of resources producing alternative conceptions. Phrased differently, if teachers or student teachers (who will become future teachers) do not fully hold a sophisticated subject matter knowledge and think their existing conceptions are correct, they may engender students' alternative conceptions[6]. For example, Çalik and Ayas[6] reported that senior science student teachers and grade 8 students had almost similar alternative conceptions. For this reason, student teachers' alternative remedial conceptions would be worthwhile to prevent teacher-based alternative conceptions soon.

Chemistry, which contains many abstract concepts, is viewed as a difficult subject[7,8]. Inasmuch as chemistry literature, students mainly hold alternative conceptions of the following subjects or find them difficult: chemical equilibrium, acid and bases, stoichiometry, electrochemistry, the structure of matter, chemical bonds, burning, physical and chemical change, dissolution and solutions, thermodynamic, compounds and mixtures[9]. Amongst these subjects, electrochemistry is the most difficult topic to teach and understand for teachers, student teachers and students[7,10-12]. For instance, Lin *et al.*[13] secondary school students observed that the electrochemical cells and electrolytic cells as a tough topic since concepts 'electricity and oxidation-reduction' are involved in these subjects. Enabling science student teachers to have a chance for multiple learning styles[14,15], the authors assume that their sample's alternative conceptions will be fully eliminated. Hereafter, there is a research need to explore this hypothesis.

Literature review

Students' alternative conceptions about electrochemistry: Because of complex structure of 'electrochemistry', several studies have been conducted on its various concepts. These alternative conceptions are outlined in Table-1. Further, their sample range is varied: high school students[16-18], introductory college chemistry students[19], college-level chemistry textbooks[20], senior prospective teachers[21], undergraduate chemistry students[22] and pre-college and college students in the National Youth Olympiad in South Africa[23].

TABLE-1
STUDENT' ALTERNATIVE CONCEPTIONS OF ELECTROCHEMISTRY

Students' alternative conceptions	Studies reported [Ref.]
The cathode is always negatively charged while the anode is always positively charged.	17-20
Electrons from the cathode pass the solution, travel through the solution and the salt bridge and emerge at the anode to complete the circuit.	16,17,19,21,23
The salt bridge helps the flow of current (electrons) since positive ions in the bridge attract electrons from one half-cell to another.	16,18,19
The identity of the anode and cathode in an electrochemical cell depends on the physical placement of the half-cells.	17,19,20
Salt bridge supplies the ions which are necessary to move from the cathode to the anode cup.	23
A lack of writing the cell reaction correctly.	20,22
Reduction occurs at the anode whereas oxidation occurs at the cathode.	17,19,22
Electrode that loses electrons is the cathode whilst electrode that gains electron is the anode.	22
The positively charged ions migrate toward the anode electrode, whereas the negatively charged ions migrate towards the cathode electrode over the salt bridge.	18,20
The anode electrode mass increases over time.	22

Conceptual change studies about electrochemistry: Since identifying and/or categorizing students' alternative conceptions is not enough to overcome them, now we will summarize conceptual change studies of electrochemistry. These studies have used different conceptual change methods and/or techniques: computer animations[24-26] or computer-assisted learning[27], conceptual change instruction[25,28-31], cooperative learning strategies[32], conceptual change text[33,34] and jigsaw puzzle techniques[24]. Meanwhile, they have focused on diverse samples: college students[25], undergraduate chemistry students[28], high school students[29,30,32-34], freshman undergraduate chemistry students[26], science matriculation students[27], first-year undergraduate students[24,31]. To sum up, conceptual change studies have generally concentrated on either high school or undergraduate students.

They have also often employed one conceptual change method and/or technique to facilitate students' conceptions. All of them point out that their used conceptual change methods and/or techniques are effective in remedying students' alternative conceptions. But they also report that their used techniques fail to completely overcome the students' alternative concepts of electrochemistry. Unfortunately, this may stem from structure of conceptual change method and/or technique. That is, using just one teaching method to accomplish conceptual change may in fact result in some disadvantages[35]. For example, it is generally not possible to find a course book or curriculum document that incorporates conceptual change text for all topics of study at school. In any case again students soon become bored with continued reading of conceptual change texts[36]. A similar situation applies to the repeated use of computer animation or analogy[37,38]. To prevent such problems, using two or more conceptual change methods or techniques may help students develop a better conceptual understanding because this process gives an opportunity for students to expose to an enriched learning environment.

Theoretical framework: To facilitate applicability of constructive learning theory, some models such as 3E, 4E, 5E and 7E are recommended. Despite of the fact that these models have almost similar steps, 5E is a quite popular version of constructivism[39]. Since each "E" represents part of the process of assisting students' learning sequence experiences in linking prior knowledge with new concepts, this model comprises of: engagement, exploration, explanation, elaboration and evaluation[40]. Now we will outline what is embedded within 5E learning model.

Computer animation: Computer animations are employed to afford students to visualize abstract concepts or sub-microscopic phenomena[41], because they give an opportunity for students to imagine how complex/abstract dynamic processes occur at the sub-microscopic level[19]. Animations help make abstract concepts or phenomena 'concrete', improve students' creative thinking and increase students' enthusiasms and engagement with the learning of science[42]. Thereafter, the authors here preferred the use of animations for several reasons (i) to make abstract concepts or phenomena 'concrete', (ii) to promote individual learning, (iii) to provide a better student engagement with the learning of science.

Conceptual change text: Conceptual change texts which offer more cost- and time-effective strategies, intend to replace the learner's alternative conceptions towards the consensual scientific view[43]. Although conceptual change texts are effective in attaining conceptual change[44], conceptual change texts ought to be used in conjunction with other strategies *e.g.*, group learning situations or whole-class discussions[45] to yield better student understandings. The authors here selected the use of conceptual change texts because of its economy, time-efficiency and ease of use.

Use of worksheet: To achieve effectively conceptual learning based on the tenets of constructivism, the worksheet has a great potential in guiding both students and their teachers[42]. Because the worksheet acts as a guide, students can easily follow directions given by teachers. Also, the worksheet provides students to not only summarize what they have learned but also revise their gained knowledge[46]. Further, within a collaborative small group, they are able to learn through sharing, being aware of group members' views and taking responsibilities. Since the worksheet is seen as a class task organizer, they increase positively the student attitudes towards chemistry education[42]. Thereby, the authors here preferred use of worksheet due to its time-efficiency and class task organizer.

Purpose of the study: The purpose of this study is to investigate effect of 5E learning model incorporating in different conceptual change methods such as computer animations, conceptual change text, worksheet and hands-on activities on remedying freshman science student teachers' alternative conceptions (FSSTs) of 'electrochemical cells'. The following research questions guide this study: (1) At which level does the 5E learning model influence the freshman science student teachers conceptual change of 'electrochemistry' concepts? (2) Does the 5E learning model enhance the freshman science student teachers retention of their newly developed conceptions? (3) Does the 5E learning model incorporating different conceptual change methods/techniques fully eliminate the freshman science student teachers alternative conceptions of 'electrochemistry' concepts?

EXPERIMENTAL

The context: The students initially encounter with electrochemistry at secondary school level and learn some electrochemistry concepts in grade 11 chemistry course: Faraday electrolysis laws, redox reactions, oxidation, reduction, oxidation-reduction potential, standard electrode potential, electrode, half cells, galvanic cell, electrolytic cell and electrolysis. Teacher training for science in the Turkish university that forms the context for this study comprises of a 4 year program. To enroll teacher training programs secondary school graduates should pass a high-stake nationwide examination[47]. Student teachers attend subject matter knowledge (*i.e.* chemistry, biology and physics), pedagogical content knowledge (*i.e.* teaching science, measurement and evaluation) and general culture courses (*i.e.* Modern Turkish History and Principles of Atatürk, English language, Turkish: Written and Verbal Language, History of Turkish Education). The science student teachers firstly introduce 'electrochemistry' within the context of General Chemistry III named Analytical Chemistry. This means that the freshman science student teachers do not take any course concerning electrochemistry at this level.

Sample: The sample of the study consisted of 30 freshman science student teachers (21 girls and 9 boys - aged 18 to 22 years) enrolled in 'General Chemistry Laboratory' course in fall semester of 2009-2010 academic year at Faculty of Education, Giresun University, Turkey. Since the current study evaluated student gained in conceptual understanding by means of pre-test, post-test and delayed-test scores, the research design is thus quasi-experimental in nature called 'simple casual design' by Trochim[48]. Such a research design may be seen as more validity threat in that its lack of random assignments and control group, limits confidence in assigning causality to an intervention. According to Trochim[48] views the main validity threat as being involved in an 'experiment' (*i.e.*, in this case a teaching intervention) may result in an apparent improvement in conceptual understanding. Moreover, the use of a delayed-test lessens this validity threat, because it addresses the potential of a maturation or experimental threat[42]. Since the experimental group is exposed to teaching intervention within a significant amount of time, all educators expect students to learn something about the underlying content[49]. Therefore, it is obvious that students at the experimental group outperform that in the control one on post-test[49]. For the foregoing reasons, the authors here preferred employing only one experi-mental group design without control one.

Electrochemical-cells concept questionnaire (ECCQ): A questionnaire with 6 two-tier questions was used in the study to identify students' conceptions of 'electrochemical cells'. The instrument was designed based on related literature and students' reported conceptions (Table-1). Of the two-tier questions, each question's first tier with one correct answer and distracters including alternative conceptions derived from related literature,

Item 1. In the cell diagram on the right side, the battery-cell schema is shown as $B/B^{+2}//A^{+2}/A$. Given this information, which of the following statements is true?

I. Electrode A is an anode.

II. Standard reduction potentials for each cell diagram is;

$A^{+2}_{(aq)} + 2e^- \rightarrow A \quad E^o_{red} = 0,80$ V

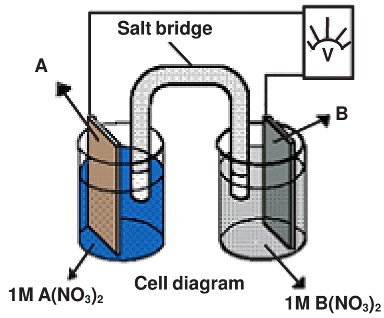
$B^{2+}_{(aq)} + 2e^- \rightarrow B \quad E^o_{red} = -0,13$ V

III. Electrode B mass increases over time.

IV. Electrode B is connected to negative input of voltmeter.

a) I and II **b)** II and III **c)** II and IV

d) I, II and III **e)** All



Please defend your response:... ... .

Item 3: Which of the following statements explains the function of the salt bridge in an electrochemical cell?

a) It absorbs complex ions from oxidation process.

b) It facilitates the flow of electrons in the solution.

c) It balances liquid levels in each half-cell.

d) It controls input and output of mobile changed ions in each half-cell.

e) It assists ions to migrate from cathode container to anode one.

Please defend your response: ....

Fig. 1. Some sample items from the electrochemical cell's related questions

concentrates on the knowledge domain, whereas the other tier relates to comprehension. To probe students' conceptions and/or alternative conceptions, such questions are generally exploited[18,50]. The questionnaire was administered as a pre-test 3 weeks before the teaching intervention. After the teaching intervention the same test was immediately employed as a post-test. Later, to determine the effect of the teaching intervention on students' retention, the same test was re-administered as a delayed-test 6 months after the intervention.

Data analysis: In analyzing the items, Çalik *et al.*[44,58] criteria were used to analyze students' responses: correct choice with correct reason (CC-CR: 10 points), correct choice with partial correct reason (CC-PCR: 9 points), correct reason (CR:8 points), incorrect choice with correct reason (IC-CR: 7 points), incorrect choice with partial correct reason (IC-PCR: 6 points), correct choice with incorrect reason (CC-IR: 5 points), correct choice with an alternative conception reason (CC-ACR: 4 points), incorrect choice with incorrect reason (IC-IR: 3 points), incorrect choice with an alternative conception reason (IC-ACR: 2 points), no response with an alternative conception reason (NR-ACR: 1 point), incorrect choice or other (IC or O: 0 point). Differences in pre-test, post-test and delayed-test scores were examined by conventional statistical means using One-Way ANOVA and a Windows version of Statistical Package for the Social Sciences (SPSS 13.0TM).

Validity and reliability: The materials improved are products of a constructivist learning environment in a graduate course where the second author acted as a lecturer. In this course, 10 graduate students (two from chemistry education, 3 from physics education and 5 from science education) discussed and commented the related materials in each week to have a better designed one[51]. Concisely, to confirm content validity, 2 chemistry educators, 10 graduate students examined the questionnaire and improved materials and confirmed their appropriateness in relation to student level, readability and comprehensibility. Further, the researchers scored all students' responses separately to provide inter-rater reliability. Their consistency was very high, *ca.* 90 %, for most items. All disagreements were resolved by negotiation. Cronbach's alpha reliability coefficient was calculated for the test's reliability was 0.65. This means that since Cronbach alpha coefficient's value falls in the scale between $0.60 \leq \alpha < 0.80$, the questionnaire is reliable to a great extent.

Teaching intervention: The teaching intervention which took place in a chemistry laboratory was carried out by the first author. Firstly, the freshman science student teachers were asked to generate their own small groups of 4 or 5 students. Because we prefer the 5E learning model, now we will present how to embed the conceptual change methods and/or techniques within 5E learning model (Fig. 2).

RESULTS AND DISCUSSION

Results of the one-way ANOVA show that there were meaningful differences amongst pre-, post- and delayed test scores (total sum of squares: 131,121, sd: 2, F: 38,937, $p < 0.05$). An indicated in Table-2, there were statistically meaningful differences between pre-test and post test in favour of post-test and between pre-test and delayed test in favour of delayed test ($p < 0.05$). However, there was no significant difference between post-test and delayed test ($p > 0.05$).

TABLE-2
RESULTS OF MULTIPLE COMPARISONS (POST-HOC TESTS)

Scores	$\bar{x}$	Factors	Mean differences	Sig.
Pre-test	3.217	Post-test	2.25*	0.00
		Delayed-test	2.20*	0.00
Post-test	6.017	Pre-test	-2.25*	0.00
		Delayed-test	-5.000	0.365
Delayed-test	5.439	Pre-test	-2.20*	0.00
		Post-test	5.000	0.365

Students' responses were also analyzed in order to determine specific alternative conceptions or difficulties based on pre-, post- and delayed-tests. These are presented in Table-3.

Since the teaching intervention especially focuses on the students' alternative conceptions, it is quite reasonable that students will progress in terms of their conceptual understanding

TABLE-3
PERCENTAGES OF STUDENTS' ALTERNATIVE CONCEPTIONS IN PRE-TEST, POST-TEST AND DELAYED TEST

Students' alternative conceptions	Experimental group (%)				
	PrT	PoT	CC	DT	R
The cathode is always negatively charged while the anode is always positively charged	33	3	+30	7	R
Electrons from the cathode pass the solution, travel through the solution and the salt bridge and emerge at the anode to complete the circuit.	17	3	+14	7	R
The salt bridge helps the flow of current (electrons) since positive ions in the bridge attract electrons from one half-cell to another	37	10	+27	13	R
The identity of the anode and cathode in an electrochemical cell depends on the physical placement of the half-cells	43	23	+20	17	R
Salt bridge supplies the ions which are necessary to move from the cathode to the anode cup.	20	7	+13	3	R
A lack of writing the cell reaction correctly	13	3	+10	10	R
Reduction occurs at the anode whereas oxidation occurs at the cathode.	7	3	+4	3	R
Electrode that loses electrons is the cathode whilst electrode that gains electron is the anode.	13	7	+6	3	R
The positively charged ions migrate toward the anode electrode, whereas the negatively charged ions migrate towards the cathode electrode over the salt bridge	17	7	+10	10	R
The anode electrode mass increases over time	3	7	-4	7	NR
Electrons move from cathode electrode to the anode electrode*	7	-	+7	-	R
Salt bridge balances liquid level in each half-cell *	13	10	+3	-	R

PrT: Pre-test, PoT: Post-test, CC: Conceptual change, DT: Delayed test, R: Retention; NR, not retain; +, positive conceptual change; -, negative conceptual change; *These alternative conceptions, unlike related literature, have firstly been identified in the pre-test

Phase	The FSSTs Role	Lecturer Role	Sample task or question
Engagement/Enter	The FSSTs are asked to answer the questions in the first stage of the worksheet. Thus, this phase purposes to not only increase students' awareness of electrochemical cells concept but also stimulate to reconsider their pre-existing ideas.	The worksheet is handed out. The lecturer creates an interactive discussion environment.	What do you think about relationship between electrochemical cell and the dead frog's leg? Why is this process called 'electrochemistry'? How do these cells in mobile phones, MP3 players, laptops and remote controllers produce necessary energy to operate them?
Exploration	The FSSTs are asked to conduct hands-on activities adapted URL-1 (2010) and use the animations. These activities aim to help them identify their own pre-existing knowledge, produce new ideas, and negotiate agreement on any disputes. Further, they are asked to write down to the worksheet what they have discussed in groups.	The lecturer follows each group and their discussions. If necessary, she asks follow-up questions to clarify the related notions but refrain from answering the questions directly.	Given the foregoing cases in Tables 1-2, how can you explain operation principle of dry cell?
Explanation	The FSSTs are required to read CCT and discuss each alternative conception and their reasons. The FSSTs address their understanding of the concept or track their correct and incorrect knowledge claims	The instructor hands out Conceptual Change Text (CCT) (see Appendix A) This phase requires a more lecturer engagement and also gives opportunities for her to directly introduce related scientific concepts, i.e. anode, cathode, function of salt bridge, conversion from chemical energy into electrical energy, electrochemical cell, electromotor power of the cell (cell potential) and so forth.	The FSSTs go over Animation 1 adapted from http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/simDownload/#electrochem
Elaboration	The FSSTs are asked to monitor Animation 2 and respond the question associated with dental caries.	The lecturer asks Question 4 and creates a class discussion environment for each concept and their reasons. She can become aware of students' elaborated ideas.	The FSSTs examine Animation 2 (see Figure 3) They fill in Questions 4-5 in the worksheet using proper concepts.
Evaluation	The FSSTs transfer their newly structured knowledge to different questions using last part of the worksheet They evaluate their own abilities and extended knowledge	The teacher asks them to transfer their newly structured knowledge to different questions She evaluate her students' abilities and extended knowledge	What is the net cell reaction? What are half-cell reactions occurring at the cathode and anode electrodes. Please draw the battery cell schema.

Fig. 2. An outline of the teaching intervention

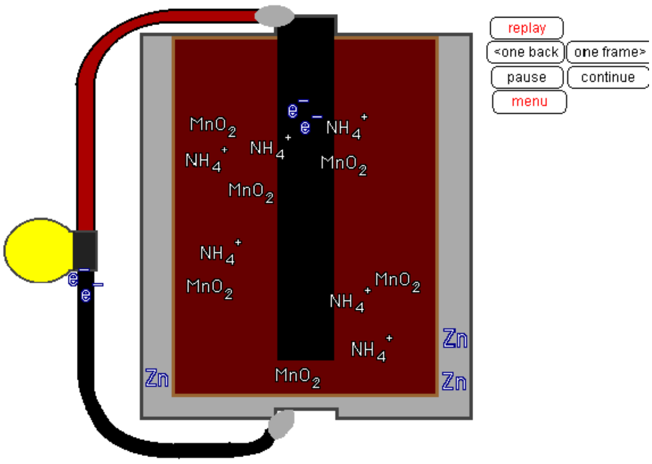


Fig. 3. A sample screen from Animation 2

of the investigated concepts[52]. That is, in the present study, results of multiple comparisons showed that there were meaningful differences between pre- and post-test in favour of post-test. This indicates that 5E learning model with different conceptual change methods and/or techniques was effective in remediating alternative conceptions and enhancing conceptual understanding. In other words, the freshman science student teachers replaced their alternative concepts with the scientific one after the intervention. This situation may result from soft-core structure of the alternative conceptions stated by Lakatos[53]. Since there was no meaningful difference between post-test and delayed test, this means that the 5E learning model assisted the freshman science student teachers in retaining their newly gained conceptions in long-term memory even 6 months after the teaching intervention, except for the alternative conception 'the anode electrode mass increases over time'. Phrased differently, the newly structured scientific conceptions in cognitive system outweigh the alternative conceptions[54]. In the cognitive system of the freshman science student teachers, the various types of knowledge, i.e. alternative conception, scientific conception and so forth, exist and compete with each other. Thereby, since this process is a struggle in which the strongest knowledge dominates, the teaching intervention seems to have helped the freshman science student teacher to achieve this tough struggle. Nevertheless, as seen from Table-3, the alternative conceptions seem to slightly dominate in some cases, especially in delayed test.

As seen in Table-2, there was a decrease in mean score of delayed test as compared with post-test. In fact, this is obvious that the freshman science student teachers might have forgotten some concepts. As a matter of fact, the science education literature reports that we often see minor decreases in students' conceptual understanding over time after an intervention[37,55,60]. Likewise, it can be concluded that some of the freshman science student teachers conceptions tended to slightly return their earlier alternative conceptions (Table-3).

Even though the authors assumed that their sample's alternative conceptions would be fully eliminated using within two or more conceptual change methods and/or techniques embedded within the 5E learning model, this hypothesis seems to have run only two of the freshman science student teachers alternative conceptions (Table-2). This also supports the notion that the alternative conceptions do not emerge from only one resource[5,6]. At least it can be deduced that the enriched learning environment was somewhat effective in frustrating teacher-based or instruction-based alternative conceptions.

As seen from Table-3, percentages of some of the freshman science student teachers alternative conceptions in the delayed test were less than those in the post-test. This may stem from the effect of the teaching intervention. That is to say, the teaching intervention might create a disequilibrium environment for students so that over time, their conceptual understanding changed towards scientific ones as a result of the intervention. In other words, the teaching intervention may have helped them to rediscover their knowledge to reach equilibrium in the long-term memory[37].

In this study, two new alternative conceptions have been detected in the pre-test: 'Electrons move from cathode electrode to the anode electrode' and 'Salt bridge balances liquid level in each half-cell'. Indeed, these two alternative conceptions seemed to fully have eliminated after the teaching intervention (Table-3). The alternative conception ''Electrons move from cathode electrode to the anode electrode' may result from confusing the electrochemistry cell with an electric circuit. That is, physics textbooks generally use the following statement to describe the electric circuit: the direction of electrons is from the minus pole to the plus pole[56]. In a similar, the alternative conception 'salt bridge balances liquid level in each half-cell' may stem from electrochemical cell models (in which equal liquid level in each half-cell is generally used) drawn by instructor or chemistry textbooks.

Classifying the alternative conception 'The anode electrode mass increases over time' as Not Retention (NR) may be seen a pitfall of the teaching intervention. Instead of expecting to observe the anode mass change, the freshman science student teachers should have been improved a graphical for anode electrode mass versus time. Hence, they may have had an opportunity to relate their conceptual understanding to graphical one. In fact, some studies report that algorithmic, conceptual and graphical understandings do not presuppose to each other[57]. Therein, further studies should be undertaken to investigate this hypothesis on how the teaching intervention affects the participants' conceptual, algorithmic and graphical comprehension.

Since teachers tend to teach the way they were taught[58,59], undergraduate courses should be firstly taught in a student-centered design. Further, since some teacher training courses, *i.e.* Science Teaching I-II, Instructional Technologies and Material Development, require the student teachers to improve their own materials, these materials may be uploaded to an open-access web-site. Thus, whenever teachers or student teachers need such material to enrich their learning and teaching environments, they can exploit them easily. This also mitigates their complaints on busy schedule, over-crowded curriculum, their vague ideas of theoretical framework and practices[58]. Finally, because the teachers are seen as the most important component in teaching procedure, graduate programmes may give opportunities for them to keep up with new teaching and learning trends. Therefore, they should be encouraged to enroll such programme.

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