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ORIGINAL ARTICLE

Exploratory Study to Determine the Effectiveness of Discussion Sessions as a Teaching Strategy on the Concepts of Spontaneity

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ABSTRACT

An exploratory study was to determine the effectiveness of discussion sessions as a teaching strategy of thermodynamics in basic physical chemistry of fundamental concepts in this area as spontaneity by explaining students according to their ideas. A previously validated questionnaire was used as an instrument on thermochemistry, enthalpies of bonding, and Gibbs function. The performance of the students who participated in the intervention was compared with that of a control group to which the afore mentioned teaching strategy was not applied. The students of the intervened group explained with a higher academic level the concept of spontaneity than those of the control group reaching the level of the development of the process of effective chemical reasoning (DECRP) of the taxonomy of barrow and bloom.

KEY WORDS: Chemical bonding; Gibbs function; spontaneity; thermodynamics

INTRODUCTION

An essential element of learning and teaching in the 21st century is a dialogic mode of interaction, which engages students in deliberative interaction about the nature of science and to build a deeper and more meaningful understanding of it. According to constructivism, it is important to design a didactic sequence where it is possible to allow students to be the protagonists of the class and see themselves in the possibility of working collaboratively. Self-regulation and self-assessment skills are necessary for adaptive learning, resilience, and autonomy (Giammatteo and Obaya-Valdivia, 2018). In the field of chemical education, various investigations indicate that after a traditional instruction of chemistry students often has conceptual errors (Herron, 1996) and failures in the integration of their ideas according to the current theoretical-conceptual frameworks (Özmen, 2004). One area of research that has attracted much attention in chemistry education is the study of problem solving versus conceptual learning, it has been found that success in solving mathematical problems does not indicate competence in handling the scientific concepts involved in it (Nakhleh and Mitchell, 1993). Chemistry students have problems with chemical concepts and misconceptions are abundant in many areas (Furio and Calatayud, 1996). Conceptual errors or misconceptions refer to misunderstandings of ideas that do not agree with scientific views. Various terms have been used for these misunderstandings, such as: Pre-conceptions, alternative conceptions, alternative frameworks, student descriptions, and explanatory systems (Nakhleh, 1992; Sulaiman et al., 2012). We consider the term misconception when it denotes a misunderstanding of a concept by the student if the source of that misunderstanding is personal experience or prior instruction (Bodner, 1986). By preconception in describing an idea, a student is faced with a general chemistry instruction (Tümay, 2016). Pre-conceptions may or may not be misconceptions depending on whether they agree with scientific understanding (Koedinger and Nathan, 2004). Students' conceptions of thermodynamics have been the subject of various studies, for example, at the upper secondary level (Boo, 1998) and at the university level (Teichert and Stacy, 2002). Establish that there is evidence that students have serious misconceptions (Greenbowe and Meltzer, 2003) of fundamental concepts in this area.

METHODOLOGY

From the premise that student learning improves when we have explicit prior knowledge, explanation, and discussion of their ideas, and compare them to those that have been covered in class, the challenge for teachers is to attend to students' preconceived ideas to design learning experiences that help students develop scientific ideas. (Newton et al., 1999; Driver et al., 2000).It is necessary to investigate these preconceived ideas, explanations of the students, and integration of their ideas for the design of a strategy of thermodynamics that allows to improve the understanding of the students in concepts such as spontaneity. The proposal was made with a sample

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of 46 students (58% women and 42% men), with an average age of 19 years old (Figure 1), from the second semester of the diagnostic biochemistry career. They gave their informed consent to participate in this study and were all volunteers. In the subject of basic thermodynamics of the corresponding diagnostic biochemistry curriculum, in the semester 2022–1 at the Faculty of Higher Studies Cuautitlán (FES-C UNAM). The subject is taught with 2 h of theoretical class and 2 h of problem workshop per week for 16 weeks covering the semester. The group was divided into two sections, the experimental (N = 19) and the control (n = 27) (Figure 1). The topic of bonding energies and spontaneity was taught in 10 h of class. In the experimental section, 2 h of discussion were held, one on enthalpy of bonding and another hour on spontaneity and free energy change, these discussion sessions were held during the hours assigned to the topic of binding energy and spontaneity. In addition, additional teaching support material was provided to students, from the texts most used in the subject (Ball, 2004; Chang, 2010; Levine, 2006), and they were always performed with the same teacher. During the discussions, students were encouraged to explain, in the form of collaborative learning, their concepts and the integration of their ideas, as well as those of the other participants, building, clarifying, and expanding among themselves (Özmen, 2004), the various concepts were discussed. Both sections attended the same theory classes in which the topic of bond energy and topics of thermodynamics as Gibbs free energy change and spontaneity, in about 10 h.

The difference between the experimental section and the control was the 2 h of additional discussion. Every concept discussed in the experimental section was covered in the control section, although not at the same level of detail. However, some topics covered in the control section, such as heat capacity and work, were not covered in the experimental section. The experimental section spent more time on few concepts, but the concepts of interest in this research were reviewed in both sections. A record was made of the discussion sessions with the experimental group, on doubts, questions, comments, clarifications, explanations, etc., most frequently requested, required, by the students of this section to establish which conceptual errors occurred more frequently and that hindered the integration of their ideas and scientifically accepted concepts. Interviews were also conducted before and after the discussion sessions (Figure 2), with 21 students, nine from the experimental group and 12 from the control group to determine their preconceptions and how these had changed during the progress of the topics studied and if they considered the collaborative work, they had developed useful.

RESULTS AND DISCUSSION

The concepts of binding energy and spontaneity were reviewed using a questionnaire-type instrument, previously validated on thermochemistry, enthalpies of bonding, and spontaneity. The instrument with four quantitative reagents (paragraphs 1, 2, 3, 4, 7, and 9) and six qualitative reagents (paragraphs 5, 6, 8, and 10) of Appendix 1 was applied in this exploratory study.

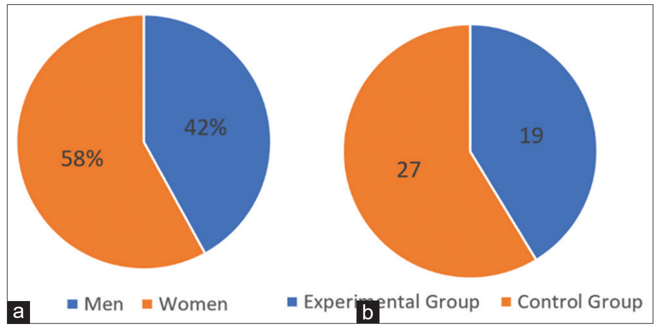

Figure 1: (a) Percentage of gender of students and (b) number of students in the experimental group and control group

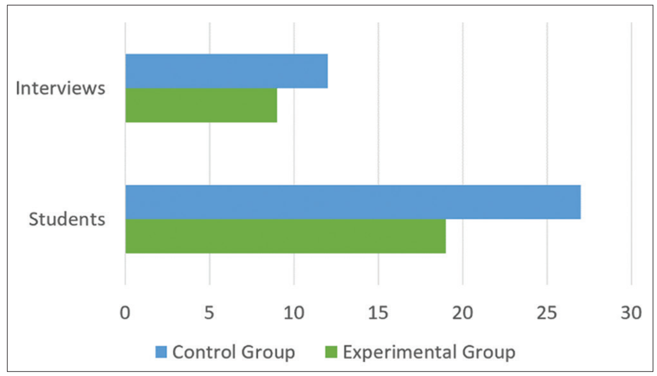

Figure 2: Number of interviews conducted with students in the experimental group and control group

Students in the experimental group performed significantly better than students in the control group in both quantitative and qualitative aspects related to binding energy. This result was not expected, since the research emphasizes the qualitative aspects, especially the concept of spontaneity, and was only considered an advance in this aspect (Item 5 of the questionnaire). This can be explained by certain studies that consider that there is a better performance of students in quantitative problems when the conceptual understanding of basic science ideas is increased (Rickey, 1999; Koedinger and Nathan, 2004). In terms of free energy change and spontaneity, both the experimental group and control group students calculated the standard free energy change of a reaction and calculated the temperature range for which a given reaction is spontaneous. There are significant differences for the solution of qualitative reagents. For the students of the control group, the qualitative part was of great difficulty, especially related to spontaneity. Only one student in the experimental group could not complete the requested information, and two students got the ΔS sign wrong (Figure 3).

In the final examination of the subject, the average for the control group was 61.41 points (σ = 14.79), while for the experimental group, it was 71.68 points (σ = 16.73), Figure 4.

The results of the interviews indicate that students have many conceptual errors before reviewing concepts both in class and in discussion sessions, so the results of these interviews are not statistically significant. They are significant for the interviews

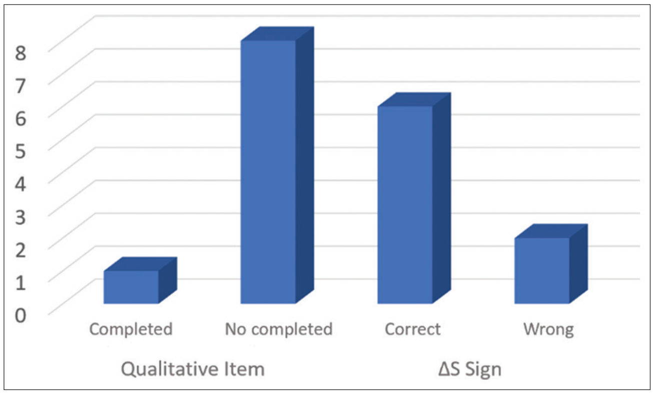

Figure 3: From the control group, one student did not complete the qualitative items and two students were wrong in the sign of ΔS

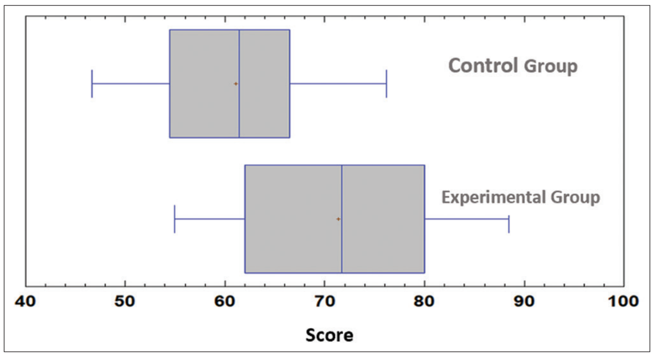

Figure 4: Box and Whisker plot of the score obtained for the test applied to the experimental and control groups

that were conducted after the discussion sessions, especially for the students of the experimental group (nine students) where there is a greater advance in the understanding of the concept of spontaneity and the integration of ideas than in the students of the control group based on the level of depth of the argument in their answers. For this, the results of the questionnaire in Item 5, which is qualitative, where students explain their ideas, were determined based on the taxonomy of barrow and bloom (Vargas-Rodríguez et al., 2021), the level of structuring of students' knowledge for an effective process of chemical reasoning such as the development of self-directed learning skills and motivation to learn by observing that the experimental group reaches an effective chemical reasoning development. This was done after the discussion sessions of the items, in the form of collaborative learning, the various concepts that were discussed where students are asked to indicate whether the following processes can be labeled as spontaneous under the following conditions:

1. A process in which ΔH is positive at constant v and p

Students felt that spontaneity requires ΔH be negative if the pressure and entropy are constant. Since we do not know the restrictions in p and S, there is no requirement that this process *should* be spontaneous.

2. An isobaric process in which ΔU is negative and ΔS is 0

The students pointed out that an isobaric process has $\Delta p = 0$. We are also given a negative ΔU and $\Delta S = 0$. Unfortunately, the condition of negative ΔU spontaneity requires an isochoric condition (i.e., $\Delta V = 0$). Therefore, we cannot say that this process *must* be spontaneous.

3. An adiabatic process in which ΔS is positive, and the volume does not change

The students concluded that an adiabatic process implies $q = 0$, and with volume not changing we have $\Delta V = 0$; therefore, $w = 0$ and therefore $\Delta U = 0$. The constant U and V allow us to apply the strict entropy spontaneity test: if $\Delta S > 0$, the process is spontaneous. Since we are given that ΔS is positive, this process must be spontaneous.

4. An isobaric and isentropic process in which ΔH is negative

The students concluded that isobaric and isentropic imply $\Delta p = \Delta S = 0$. These are the appropriate variables to use the enthalpy spontaneity test, which requires ΔH to be <0. In fact, this is the case, so this process must be spontaneous.

Observing, based on their conclusions, students reached the level of developing the process of effective chemical reasoning (DECRP) due to the level of reasoning of their answers.

Representative student comments related to the strategy employed:

Sometimes, it is a bit complicated to go at the same pace for the understanding of the issues; however, thanks to the opportunity to work as a team this disadvantage becomes less noticeable because among the team, we can help us solve doubts.

If we talk about the workload, we believe that it was well distributed, in the classes both the teacher and the students were involved, the books and the teacher explained step by step some procedure in the discussion sessions, or, concepts that helped to reinforce topics seen in class, we can say that mostly everything shared was understandable and helpful.

The books were used in various classes to explain the topics and related formulas, and group discussions were held that complement the explanations given.

Teamwork was a great way to support each other, as it is very difficult to understand certain topics, but communication was always good with both the teacher and classmates.

CONCLUSIONS

Students who performed collaborative work and participated in discussion sessions as an instructional strategy performed significantly better than students who participated in the section that only had traditional instruction in the basic thermodynamics subject, both in the written assessments and in the interviews that were conducted. Students achieved a better understanding of the concept of spontaneity after engaging in an instructional strategy that motivated them to explain their concepts, reaching the level of effective chemical reasoning. (DECRP) because of the level of argumentation of their answers.

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This work demonstrates the effectiveness of the explanation and integration of ideas among students in a subject of physical chemistry, which is traditionally considered one of the most difficult subjects in the curricula of careers in chemistry, so the use of this strategy can avoid conceptual errors in thermodynamics favoring the academic performance of students and reduce the failure rate in this subject.

The interviews illustrate how ingrained are student preconceptions that interfere with learning and how discussion sessions enable students to reason better and explain their own ideas in relation to concepts seen in class.

On the other hand, the importance given to listening carefully to students can be revealing that the lecture or oral presentation of the teacher, which is still usual as a teaching vehicle, such a technique is no longer the most advisable in all cases to promote learning. It can be considered that this exploratory research met the proposed objectives and that this work can give the guideline to further research.

ETHICAL STATEMENT

The students agreed to participate in this exploratory research and volunteered. This study was approved by the authors' university.

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APPENDIX

Appendix 1: Thermochemistry, enthalpies of bonding, and spontaneity

1. Deduce the standard enthalpy change for the process of the standard enthalpy of data found in books
   $2CH_4(g) \text{->} C_2H_6(g) + H_2 (g)$
2. It is possible to calculate ΔH for the reaction of the bond energy. Explain your answer
   $C_2H_5OH(l) + O_2(g) \text{->} CH_3COOH(l) + H_2O(l)$
3. Calculate from enthalpies of bond the heat of combustion of methane to CO_2 (g) and H_2O (1) assuming the structure of the molecule CO_2 is 0 = C = 0. b) How does this estimate compare to the observed value?
4. Why is the entropy of the elements at their standard pressure at normal (i.e., ambient) temperatures not equal to zero?
5. Indicate whether the following processes can be labeled as spontaneous under the following conditions:
   a. A process in which ΔH is positive at constant v and p
   b. An isobaric process in which ΔU is negative and ΔS is 0
   c. An adiabatic process in which ΔS is positive and volume is not change
   d. An isobaric and isentropic process in which ΔH is negative
6. Demonstrate that the free adiabatic expansion of an ideal gas is spontaneous
7. Calculate $\Delta G°$ (25°C) For the following chemical reaction, which is the hydrogenation of benzene to produce cyclohexane
8. Explain why the conditions for using $\Delta S = 0$ as a condition of strict spontaneity imply that ΔU and ΔH are equal to zero
9. Use the bonding energies listed in the books to calculate ΔH° 298 for the reaction compare with the actual value 51 kJ/mol
   $CH_3CH_2OH(g) \rightarrow CH_3OCH_3(g)$.
10. Set true or false of the following sections. Argue your answer
    a. The term standard state implies that the temperature is 0°C
    b. The term standard state implies that the temperature is 25°C
    c. The standard state of a pure gas is pure gas at a pressure of 1 bar and temperature T