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# Picturing the thermodynamic universe with Frida Kahlo

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**Abstract.** Bringing arts to the science classes remains as a challenging idea. The illustration of a concept with an original painting would bring unexpected advantages. Here we present the use of a painting of Frida Kahlo to illustrate the concept of the thermodynamic universe the surroundings. Such concept is not deeply treated in most textbooks, and it is essential now of analysis of a thermodynamic system. Because of the use of this visual aid, our students were able to distinguish several possible thermodynamic universes, depending on the objective of their study, gaining a more insightful approach than that usually obtained with classical pictographic representations in physical chemistry textbooks.

## 1. Introduction

The 1<sup>st</sup> and 2<sup>nd</sup> laws of thermodynamics constitute the core topics in physical chemistry and represent the main conflicts in the understanding [1-4], due to the abstract nature of concepts and their physic and mathematical representations [5]. For the comprehension of the different thermodynamic concepts, students must deal with the transference of matter and energy, implying the identification of the system and surrounding involved in their analysis. Depending on the level of expertise (novice or expert), students use image-schemas that can be referred as metaphorical expression in solving problems in thermodynamics. These conceptual metaphors serve as a resource to understand abstract concepts, verbally formulated scientific principles, or images of physical chemistry situations [6,7].

The description of the thermodynamic universe is the first issue in the application of the thermodynamic theory. The concept of thermodynamic universe, space where the Second Law of Thermodynamics holds, it is composed of the system, the surrounding, and the frontier. The permeability of the frontier determines the kind of system we are working with, depending on the feasibility of transference of matter and/or energy. On the other hand, the surroundings constitute the part of the universe that interact with the system receiving or donating matter and/or energy or impeded to do so in the case of an isolated system. These concepts are interpreted and reinterpreted from the Thermodynamic chapter in textbooks, in which different levels of representations are needed for the adequate understanding of natural phenomena [8], either separated or integrated to explore multilevel thinking [9]. Representation's density in physical chemistry textbooks can account for up to 95% of the sampled pages [10].

## 2. The description of the thermodynamic universe in textbooks

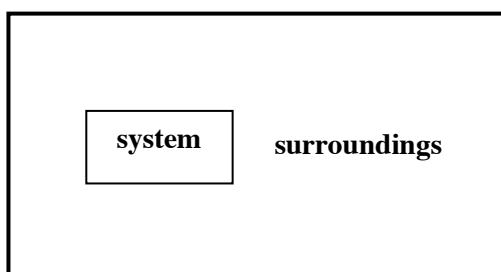
We carried out a systematic review of 14 [11-24] textbooks on physical chemistry and thermodynamics to identify the definition and illustrative representation given to the thermodynamic universe concept.



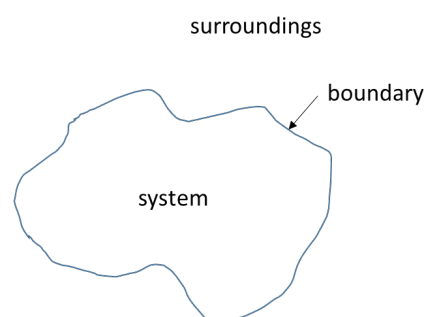
Ten of these textbooks considered the surroundings just as “the rest”, with no additional explanation, and only few go a bit further by explaining which part of “the rest” should be considered as surroundings. For example, Levine [20] limits the definition saying “The parts of the universe that can interact with the system”; Atkins [11] gives another point of view stating that “The surroundings comprise the region outside the system and are where we make our measurements”; O’Connell and Haile [23] are also more explicit putting clear that “The surroundings include only that part of the universe close enough to affect the system in some way”. In the classical textbook of Laidler [19], the surroundings are not specifically defined, but several examples are given making clear that interaction with the system is needed.

### 3. Pictograms as the minimum description of the thermodynamic universe

Poirier [25] compared several definitions coming from different textbooks and propose to reinforce the idea that the system and surrounding considered together should be an isolated system, and hence a part of the Universe in which the 2<sup>nd</sup> law of thermodynamics holds. In this regard, proposed the pictogram depicted in Figure 1.



**Figure 1.** Pictogram of the thermodynamic universe proposed by Poirier [25]. The thick line denotes that the thermodynamic universe is isolated, in accordance with the 2<sup>nd</sup> law of thermodynamics.



**Figure 2.** Common scheme example used in Physical Chemistry textbooks to illustrate the thermodynamic universe.

This pictogram is usually employed in the presentation of the 2<sup>nd</sup> law of thermodynamics, stating that the limit of the total system not only prevents matter exchange, but also energy exchange. Another point that Poirier pointed out is that the definitions of system and surrounding should be “wise” [25] in the sense that should contain information enough to answer the questions proposed, and not filled of unnecessary details.

The usual pictogram to describe the thermodynamic universe usually consist in a simple separation between an enclosed system surrounded by “the rest” and, with more or less beauty, they look like the one depicted in Figure 2. Interestingly, this pictogram is seldom used independently that the textbook goes further in relation to the definition of surroundings. Clearly this pictogram is not adequate to sustain the detailed definition treated by the few authors already mentioned. The schematic presentation usually employed in most textbooks (Figure 2) reinforces this misconception, as the absence of no physical limit to the surroundings is in line with the idea of being all “the rest”.

To discuss this topic with the students during the lecture, we usually employ the example of a beaker in which the reaction (object of our study) takes place. The beaker is placed in a thermostat, and we explain why the thermostat constitute the surroundings. This is usually understood by the students with no difficulty. However, when the students realize that the thermostat can provide a constant temperature because it is connected to the electric line, immediately say that the electric line should also be included in the surroundings. To push them further, we remind them that the electric line is fed from the central electric power which is fed by petrol ... and so on. At this point, students realize that a stop is necessary, a point where the “wise” definition suggested by Poirier effortless arises.

#### 4. A different kind of pictographic representation

In our physical chemistry course for biochemistry majors at the “Facultad de Ciencias, Universidad de la República, Uruguay”, we have been employing an alternative visual aid for 6 years. These students have to deal with very complex systems (biological, biochemical), and the goal was to improve their understanding of the concept of thermodynamic universe and the complexity of its representation depending on the system studied. To determine the impact of using alternative illustrative representation in the student’s understanding of the thermodynamic universe concept, the students completed an in-class questionnaire before instruction (pre-questionnaire) and a modified version of the questionnaire after instruction (post-questionnaire). Lectured-based instruction included a discussion about the components of the thermodynamic universe concept (system, frontier and surrounding) using an alternative representation to those usually employed in most textbooks.

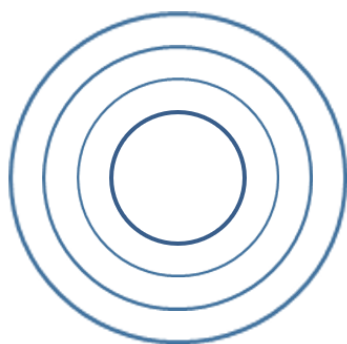
During the instruction we introduce the Frida Kahlo’s painting “El abrazo amoroso del Universo” (The loving embrace of the Universe) as a visual aid to reinforce the concept of the thermodynamic universe (Figure 3). We describe the interactions represented in the picture, the context where the picture was painted and the relationship among the characters. In this painting, Frida Kahlo is embracing her husband Diego Rivera in a mother-child attitude. Both are embraced by the Mother Earth, which in turn is embraced by the Mother Universe, which hold them all. This painting represents several cultural issues from Mexico, but the general presentation much alike some kind of concentric circles, and different possible combinations of systems and surroundings. For example, if the focus of our study is Frida and Diego relationship, Mother Universe does not directly interact with them, and can be taken out from the Thermodynamic Universe in this study, as it was in the case of the example of the electric power plant mentioned above.



**Figure 3.** “The loving embrace of the Universe”, by Frida Kahlo (1949). Original image file authored by Ambra75, and uploaded to Wikimedia Commons on 0.3.05.2018, taken at the Mostra di Frida Kahlo al Mudec di Milano, and licensed under the Creative Commons Attribution-Share Alike 4.0 International license.

#### 4.1. Evaluation of the new pedagogical approach

Prior to instruction, we asked students about their previous knowledge of thermodynamics and thermodynamic universe (system, frontier and surrounding). After instruction, we asked the students to describe the three components of the thermodynamic universe using the painting and a simplified representation of concentric circles (Figure 4), and to explain how many thermodynamic universes they identified from the representations.



**Figure 4.** Concentric circles to illustrate different combinations of systems and surroundings.

In a limited survey was done one of the years, with the participation of 18 students from the physical chemistry course for biochemistry majors at the “Facultad de Ciencias, Universidad de la República, Uruguay”. The results of students’ responses to the pre-questionnaire, shown that 10 students defined surroundings as “the rest” or “everything that is not the system”, 5 students included conceptual errors like “the surroundings are the system + frontier” or “is the part of the system that we are not interested in”, and 2 students were able to identify that the surroundings somehow interact with the system. One student did not answer the survey. After the instruction, the 2 students that gave correct answers went further and recognized that in both pictures it was possible to describe different thermodynamic universes, depending on what is the objective of the study. Interestingly, most of the students that defined the surroundings as “the rest” arrived at the conclusion of the existence of many possible definitions of thermodynamic universes only in the Frida Kahlo’s painting, and only few of them recognized the Figure 4 as a pictogram of the painting. From the group of 5 students that gave incorrect answers, 4 of them arrived at a similar conclusion that the rest of the students, while the other still gave an incorrect answer. Finally, the student that did not answer the pre-questionnaire recognized the existence of multiple possible thermodynamic universes only in the picture of Frida Kahlo.

## 5. Discussion

The possible link between science and arts can be viewed from different stand points. According to Hoffmann and Laszlo [26], the representation of the chemical structures through pictograms fits the definition of art in the sense that extract the essence from the natural complexity to convey an idea. Just in the opposite side, Luisi and Thomas [27] draw attention on the excessive pictorialization of the chemical sciences, leading to an oversimplification of the natural complexity.

In the example under consideration, we manage the complexity of a piece of art (a painting) to extract an idea, and later to provide a pictorial view of this complexity. The advantage of this procedure is that the original complexity, which is well understood, can be translated to another complex system which the students are being presented, may be for the first time. Surprisingly, most of the students that could identified the components from Frida Kahlo’s painting were not able to describe them from the new pictogram provided. Somehow, the excessive pictorialization mentioned by Luisi and Thomas [27] is really against the view of the complexities of the real world.

We have also employed other artistic objects to illustrate science concepts. For example, in our class about self-assembly, we use an image of the piece “Beehive” [28] to show how several pieces of bricks (construction units) adequately assembled to produce a novel structure, a beehive.

## 6. Conclusions

The approach to use real art objects has several advantages, the main one is that we may try to understand our living world learning from its own and natural complexity. In the case of the thermodynamic description of the universe, we should just understand which part of the cosmic Universe does not add nothing to the study of our system to take it out from our thermodynamic universe. This is enough simplification.

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## References

- [1] Chang W 2011 Teaching the first law of thermodynamics via real-life examples *The Physics Teacher* **49** 231-233
- [2] Hadfield L C, Wieman C E 2010 Student interpretations of equations related to the first law of thermodynamics *Journal of Chemical Education* **87** 750-755
- [3] Tatar E, Oktay M 2011 The effectiveness of problem-based learning on teaching the first law of thermodynamics *Research in Science & Technological Education* **29** 315-332
- [4] Leinonen R, Asikainen M A, Hirvonen P E 2015 Grasping the second law of thermodynamics at university: The consistency of macroscopic and microscopic explanations *Physical Review Special Topics - Physics Education Research* **11** 020122
- [5] Bain K, Moon A, Mack M R, Towns M H 2014 A review of research on the teaching and learning of thermodynamics at the university level *Chemistry Education Research and Practice* **15** 320-335
- [6] Jeppsson F, Haglund J, Amin T G 2015 Varying use of conceptual metaphors across levels of expertise in thermodynamics *International Journal of Science Education* **37** 780-805
- [7] Jeppsson F, Haglund J, Amin T G, Strömdahl H 2013 Exploring the use of conceptual metaphors in solving problems on entropy *Journal of the Learning Sciences* **22** 70-120
- [8] Johnstone A H 1991 Why is science difficult to learn? Things are seldom what they seem *Journal of Computer Assisted Learning* **7** 75-83
- [9] Taber K S 2013 Three levels of chemistry educational research *Chemistry Education Research and Practice* **14** 151-155
- [10] Nyachwaya J M, Wood N B 2014 Evaluation of chemical representations in physical chemistry textbooks *Chemistry Education Research and Practice* **15** 720-728
- [11] Atkins P, de Paula J 2014 *Atkins' Physical Chemistry* (New York: W.H. Freeman & Co.)
- [12] Ball D 2014 *Physical Chemistry* (Stamford: Cengage Learning)
- [13] Çengel Y A, Boles M A 2011 *Thermodynamics: An Engineering Approach* (Boston: McGraw-Hill)
- [14] Engel T, Reid P J, Hehre W 2013 *Physical Chemistry* (Boston: Pearson)
- [15] Glasstone S 2007 *Thermodynamics for Chemists* (Delhi: Narahari Press)
- [16] Haynie D T 2008 *Biological Thermodynamics* (Cambridge: Cambridge University Press)
- [17] Kaufman M 2002 *Principles of Thermodynamics* (New York: CRC Press)
- [18] Kondepudi D, Prigogine I 2014 *Modern Thermodynamics: From Heat Engines to Dissipative Structures* (West Sussex: Wiley)
- [19] Laidler K J 1978 *Physical Chemistry With Biological Applications* (California: Benjamin/Cummings Publishing Company)
- [20] Levine I N 2009 *Physical Chemistry* (Boston: McGraw-Hill)
- [21] Moran M J, Shapiro H N, Boettner D D, Bailey M B 2010 *Fundamentals of Engineering Thermodynamics* (New Jersey: Wiley)
- [22] Mortimer R G 2008 *Physical Chemistry* (San Diego: Elsevier Science)
- [23] O'Connell J P, Haile J M 2005 *Thermodynamics: Fundamentals for Applications* (Cambridge: Cambridge University Press)
- [24] Sun S F 2004 *Physical Chemistry of Macromolecules: Basic Principles and Issues* (New Jersey: John Wiley & Sons)
- [25] Poirier B 2014 *A Conceptual Guide to Thermodynamics* (West Sussex: Wiley)

- [26] Hoffmann R and Laszlo P 1991 Representation in Chemistry *Angewandte Chemie International Edition in English* **30** 1-16
- [27] Luisi P-L and Thomas R M 1990 The pictographic molecular paradigm *Naturwissenschaften* **77** 67-74
- [28] Florschutz J 2008 Sculpture (Portland: James Florschutz Studio) Consulted on: <https://jamesflorschutz.com/filter/SCULPTURE/TITLE-BEEHIVE-2008SIZE-32-X-40-X-40-MATERIALS-MIXED-MEDIA-ASSEMBLAGE>