# Building the Conceptual Profile of Chemical Analysis: The Sociocultural Domain

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## Abstract

*The conceptual profile framework is based on the assumption that people exhibit various modes of thinking that are used in various contexts. Chemical analysis is a central concept of chemistry and is characterized by a worthwhile polysemy, which is observed in both scientific and everyday language, such as the one employed in science classrooms. The purpose of this study is the development of the conceptual profile of chemical analysis, as a tool for characterizing the heterogeneity of students' ways of speaking and, therefore, thinking about it. The conceptual profile is composed of several zones. Each zone represents a specific way of thinking about the given concept and emerges from the study of this concept in different genetic domains. In the present study, the concept of chemical analysis is explored within the sociocultural genetic domain via examination of relevant secondary historical and epistemological literature. As a result, the following six conceptual profile zones which are related to the foundations of the concept of chemical analysis are proposed: chemical analysis as (a) everyday practices, (b) alchemist analysis, (c) empirical techniques, (d) classical analysis, (e) classical instrumental analysis and (f) a contemporary tool for society. Refinement and enrichment of the above proposed zones will follow by studying the ontogenetic and microgenetic domains of chemical analysis.*

**Keywords:** *conceptual profile, chemical analysis, sociocultural domain*

## 1. Introduction

Scientific thinking is one of the key objectives of education in the 21st century worldwide [1,2,3]. As far as chemistry is concerned, chemical thinking is defined as the set of theoretical concepts and experimental procedures of chemistry that are developed and applied in order to achieve the main purposes of the discipline, i.e. synthesis, analysis and transformation [4]. Much of the research on chemical thinking has detected a great heterogeneity in students' ways of thinking about various chemical concepts [5,6,7,8,9], which can be very challenging for chemistry teaching and learning [10]. The conceptual profile framework is a methodological tool that can help teachers gain awareness of the different ways of thinking and speaking in science classrooms and via which students enrich their thinking with more scientific ideas [11,12,13,14].

Given the above, the purpose of this study is the development of the conceptual profile of chemical analysis, which is a central concept in chemistry [4] and refers to the determination of the qualitative and quantitative chemical composition of materials and chemical substances [15]. At first, we will present the main foundations of the conceptual profile theoretical framework as developed by its pioneers. Then, we will describe the methodology of our work, followed by the presentation and discussion of the results reached, namely the description of the six zones of the proposed conceptual profile and their commitments.

## 2. Theoretical framework

The conceptual profile framework is based on the assumption that people exhibit various modes of thinking that are used in various contexts [12]. Conceptual profiles are used as a tool of characterizing the heterogeneity of thinking in a classroom [16] and are composed of several zones. Each zone represents a specific way of thinking about a given concept and emerges from the study of this concept in different genetic domains (sociocultural, ontogenetic and microgenetic) [12]. Each particular way of thinking is determined by ontological, epistemological and axiological commitments that one has about its meaning [16] and characterized by a specific way of speaking about the concept [14,17].

The main foundations of the conceptual profile framework are the following: (a) for a given concept heterogeneity in thinking is found in the population, (b) for a given concept heterogeneity in thinking is found in an individual, (c) as far as data analysis is concerned, modes of thinking and modes of speaking are considered as equivalent [12,14].

More specifically, individuals have their own conceptual profiles for different concepts, which are characterized by the different weight each zone has. These differences depend on the individual's experience, which offers more or less opportunities to apply each zone in appropriate contexts. Different individuals may exhibit similar zones and ways of thinking and speaking due to their exposure in similar sociocultural environments [11].
Moreover, someone may possess two or more differents meanings for the same concept, which are evaluated and used in appropriate contexts. After all, science itself is not a homogeneous form of knowledge and can provide different ways of perceiving the same phenomenon [18], which may coexist in a person and be used in different contexts. In addition, countless scientific words are used in everyday language and therefore have several meanings that are not always consistent with scientific understanding [11]. These different ways of thinking are often related to common sense [16].
As far as educational practice is concerned, conceptual learning aims at enriching students' conceptual profiles and at making them aware of their possession. By enriching students' conceptual profiles and especially by promoting their learning of scientific ways of thinking the relative importance of each zone changes [11]. Then, in a metacognitive process, teachers help students become aware of distinct ways of thinking and the values or criteria that can guide the choice of perspectives to address specific problems [19].
Conceptual profiles have been developed for scientific concepts such as life [11], thermal physics [20] and energy [17,21], matter (atoms, molecules) [11], substance [13,22], chemical bonds [23], chemical change [24], equilibrium [14] and chemistry in general [25]. Based on our literature research, the conceptual profile of chemical analysis has not been developed yet and, additionally, it has been many years since alternative means of assessing students' understanding of chemical analysis were considered as necessary [26].

## 3. Methodology

As mentioned above, each zone of a conceptual profile represents a specific way of thinking about the given concept and emerges from the study of this concept in different genetic domains: sociocultural, ontogenetic and microgenetic. The sociocultural domain can be explored through sources of secondary literature on the history of science and epistemological research on the concept, the ontogenetic domain is examined by literature on the alternative conceptions as well as teaching and learning and the microgenetic domain is studied by primary data collection [12].
In the present study, the concept of chemical analysis was explored within the sociocultural genetic domain via examination of (a) secondary literature on the history of science, which provides an understanding of the difficulties and changes in the way of thinking about the concept as well as the effects of these changes and (b) epistemological and philosophical sources and textbooks, which are particularly useful for understanding the attribution of the concept meaning [11,14,16]. From the entire secondary historical and epistemological literature, the following sources are indicatively mentioned: books about history and epistemology of Chemistry [History of Chemistry [27], A short history of Chemistry [28], Mendeleev's dream – the quest for the elements [29] and studies on the evolution of Analytical Chemistry [26,30,31]. Some dictionaries were also used (The Stanford Encyclopedia of Philosophy [32], Dictionary of Standard Modern Greek [33]) as well as Analytical Chemistry textbooks such as the Fundamentals of Analytical Chemistry [15].
The different ideas and definitions of analysis were grouped into categories in a dialogic way [11] based on how analysis is perceived. For each different way of thinking, the ontological, epistemological and axiological commitments were identified, which distinguish it from other ways of thinking, with the following questions, as suggested in the study of Orduña Picón, Sevian & Mortimer (pg. 11) [13]:

1. The ontological question: What kind of entities/processes does an individual commit to believe exist to make sense about what chemical analysis is?
2. The epistemological question: What is the basis on which a person justifies her/his belief that particular entities/processes exist to make sense about what chemical analysis is? and
3. The axiological question: What evaluative–affective judgments does an individual make to construct her/his relationships with entities/process to make sense about what chemical analysis is?

In a subsequent stage of the research, the conceptual profile of chemical analysis will be enriched with data from the ontogenetic and microgenetic domains, so that the existence of expanded categories will be validated and analysis will be refined, on condition that there is a constant dialogic interaction between data from each domain in order to avoid bias [13]. The ontological, epistemological and axiological commitments of each zone will also be reviewed.

## 4. Results and discussion

The qualitative analysis of the sources listed in the Methods section, resulted to the identification of a total of six zones, which comprise the conceptual profile of chemical analysis within the sociocultural domain. These zones are listed in Table 1 accompanied by their identified corresponding ontological, epistemological and axiological commitments.
The main historical and epistemological findings within the sociocultural genetic domain which explain and justify each way of thinking (conceptual profile zone) are subsequently discussed.

Table 1: Conceptual profile of chemical analysis.

| Zone | Commitments |
|---|---|
| 1. Everyday practices | Ontological: simple practices of isolation and separation of substances<br>Epistemological: direct observation - use of senses, instinct, skill, practice, experience, independently of theory<br>Axiological: use for daily and professional needs |
| 2. Alchemist analysis | Ontological: simple practices of isolation, separation and purity control of substances<br>Epistemological: direct observation - use of senses, instinct, skill, practice, experience, modifying or independently of theory<br>Axiological: metaphysical - mystical - supernatural - philosophical background, profit, fraud, suspicions |
| 3. Empirical techniques | Ontological: simple experiments - titrimetric and gravimetric techniques<br>Epistemological: direct observation - use of senses, instinct, skill, practice, experience, little use of theory<br>Axiological: logical thinking, precision, generalizations, breakdown of events into components |
| 4. Classical analysis | Ontological: titrimetric and gravimetric techniques<br>Epistemological: experiments based on physical and chemical properties (reactions), integrated into a comprehensive theoretical framework and published in scientific journals<br>Axiological: systematic analysis, similarities – differences and grouping, repeatability, verification, errors, comprehensible records and results, accuracy of the analysis and reduction of analysis time |
| 5. Classical instrumental analysis | Ontological: instrumental techniques (isolated instruments in the laboratory)<br>Epistemological: experiments based on physicochemical properties, comparison of the signal of samples and standards<br>Axiological: reduction of cost and time of analysis, non-destructive methods, low detection limits |
| 6. Contemporary tool for society | Ontological: instrumental techniques (coupled instruments in the laboratory or in field work)<br>Epistemological: development of chemometrics and other related scientific fields<br>Axiological: socio-economic dimension and R&D, specialization, collaboration, minimization of error, larger numbers of data and multidimensional information, lower detection limits, reduction of cost – time of analysis, reliability, automation, sensitivity, selectivity and optimization |

### 4.1 Chemical analysis as everyday practices

When chemical analysis is perceived as everyday practices, individuals consider simple analytical practices (isolation, separation) based on direct observation (use of senses) [27,28,29]. As such, the purpose of analysis is to meet daily and professional needs related to metals and ceramics, therefore what matters is not the method itself but its use and results. Instinct, skills, practice and experience are very much required and experimental practices are developed independently of theoretical ideas [27]. Analysis is often characterized as “art” [28] and is not anticipated as science while methods are not recorded and they are passed down orally from generation to generation instead [27]. Chemical analysis is not necessarily carried out in a specific and organized space (i.e. laboratory). Ontological, epistemological and axiological commitments of this way of thinking are presented in Table 1.

### 4.2 Chemical analysis as alchemist analysis

Similar to the zone of “everyday practices”, alchemist analysis refers to simple analytical practices (isolation, separation, purity control) based on direct observation (use of senses) [27,28,29]. However, its commitments are different (Table 1) since the purpose of alchemist analysis is the creation of the elixir of immortality, the pursuit of the philosopher's stone and the conversion of all metals into gold [27,29]. This way of thinking is largely based on by a metaphysical, mystical, supernatural and philosophical background [27,28]. Instinct, skills, practice and experience are very much required, experiments are not usually based on theory or theory is modified to fit experimental results [27]. Quite often alchemists are associated with fraud for profit and deception [28,29] and common people are suspicious of them [27]. While there is a strong symbolism in the records of methods, at the same time technology is utilized and rudimentary laboratories are created [29].

### 4.3 Chemical analysis as empirical techniques

As suggested in Table 1, empirical techniques include simple experiments based on direct observation (use of senses) and titrimetric and gravimetric techniques [27,28,29]. As such, chemical analysis aims at the determination of the composition and the concentration of specific analytes with different properties [31]. Although there is evidence of the development of the scientific method (logical thinking, accuracy, generalizations and breakdown of events into components) and experiments are recorded, there is a lack of a comprehensive theoretical framework [27,29] while instinct, skills, practice and experience are still of great importance [31]. Experiments are mostly conducted in laboratories [27].

### 4.4 Chemical analysis as classical analysis

Titrimetric and gravimetric techniques based on different physical properties (colour, odour, solubility etc.) and chemical reactions (oxidation/reduction, thermal decomposition, acid/base reactions, double replacement) constitute classical analysis [26] and they are carried out in laboratories [15]. As such, chemical analysis aims at the determination of the composition of a sample (qualitative analysis) and the concentration of specific analytes with different properties (quantitative analysis) [15,31]. As shown in Table 1, the employed methods are destructive but they have become more systematic, accurate and repeatable [29] while at the same time awareness of errors has been developed [27]. Experiments are integrated into the comprehensive theoretical framework of Chemistry as a distinct scientific area and published in scientific societies' journals [29].

### 4.5 Chemical analysis as classical instrumental analysis

Chemical analysis as classical instrumental analysis involves instrumental techniques based on the theoretical principles of (physical) chemistry as well as the comparison of the signal of samples with the signal of a standard [15,27,31] and carried out in laboratories using isolated instruments [31]. As such, chemical analysis aims at the determination of the composition of a sample (qualitative analysis) and the concentration of specific analytes with similar or different physicochemical properties (quantitative analysis) [15,31]. As shown in Table 1, methods are non-destructive and characterized by lower detection limits as well as lower cost and less analysis time [27].

### 4.6 Chemical analysis as a contemporary tool for society

As suggested in Table 1, when chemical analysis is perceived as a contemporary tool for society, the purpose of chemical analysis is to solve analytical problems arising from society, economy and R&D, to minimize analytical error and to obtain larger numbers of data as well as multidimensional information about analytes with similar or different or properties [31]. The analysis is based on chemometrics, other scientific fields (physics, mathematics, informatics, etc.), nanotechnology and robotics [27,31]. Also, in addition to the use of mainly coupled instruments in the laboratory, field work is carried out. Methods are characterized by specialization, collaboration, lower detection limits, reliability, sensitivity, selectivity and optimization [31].

## 5. Conclusions

Based on the study of the sociocultural genetic domain of the concept of chemical analysis and, more specifically, on secondary historical and epistemological literature as well as on the ontological, epistemological and axiological commitments of the different ways of thinking and speaking, the following six conceptual profile zones are proposed: chemical analysis as (a) everyday practices, (b) alchemist analysis, (c) empirical techniques, (d) classical analysis, (e) classical instrumental analysis and (f) a contemporary tool for society.

Refinement and enrichment of the above proposed zones will follow by studying the ontogenetic and genetic domain of chemical analysis [14,16]. The identified zones may then constitute the basis for probing students' thinking regarding chemical analysis.

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## References

[1] National Research Council - NRC (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.
[2] Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R. et al. (2014). Scientific Reasoning and Argumentation: Advancing an Interdisciplinary Research Agenda in Education. *Frontline Learning Research*, *2*(3), 28-45.
[3] Zhou, S., Han, J., Koenig, K., Raplinger, A., Pi, Y., Li, D. et al. (2016). Assessment of scientific reasoning: The effects of task context, data, and design on student reasoning in control of variables. *Thinking Skills and Creativity*, *19*, 175-187.
[4] Sevian, H., & Talanquer, V. (2014). Rethinking chemistry: A learning progression on chemical thinking. *Chemistry Education Research and Practice*, *15*(1), 10-23.
[5] Talanquer, V. (2013). How do students reason about chemical substances and reactions? In G. Tsaparlis, & H. Sevian, (Eds.) *Concepts of Matter in Science Education* (pp. 331-346). Springer, Dordrecht.
[6] Yan, F., & Talanquer, V. (2015). Students' ideas about how and why chemical reactions happen: mapping the conceptual landscape. *International Journal of Science Education*, 37(18), 3066-3092.
[7] Cooper, M., Kouyoumdjian, H., & Underwood, S. M. (2016). Investigating students' reasoning about acid–base reactions. *Journal of Chemical Education*, 93(10), 1703-1712.
[8] Moon, A., Stanford, C., Cole, R., & Towns, M. (2017). Analysis of inquiry materials to explain complexity of chemical reasoning in physical chemistry students' argumentation. *Journal of Research in Science Teaching*, 54(10), 1322-1346.
[9] Caspari, I., Kranz, D., & Graulich, N. (2018). Resolving the complexity of organic chemistry students' reasoning through the lens of a mechanistic framework. *Chemistry Education Research and Practice*, *19*(4), 1117-1141.
[10] Talanquer, V. (2019). Assessing for Chemical Thinking. In: Schultz M., Schmid S., Lawrie G. (eds) *Research and Practice in Chemistry Education* (pp. 123-133). Springer, Singapore.
[11] Mortimer, E. F., Scott, P., & El-Hani, C. N. (2012). The heterogeneity of discourse in science classrooms: The conceptual profile approach. *Second international handbook of science education*, 231-246.
[12] Mortimer, E. F., El-Hani, C. N., Sepulveda, C., do Amaral, E. M. R., Coutinho, F. Â., & Rodrigues e Silva, F. A. (2014). Methodological grounds of the conceptual profile research program. In *Conceptual Profiles: A Theory of Teaching and Learning Scientific Concepts* (pp. 67-100). Dordrecht: Springer Netherlands.
[13] Orduña Picón, R., Sevian, H., & Mortimer, E. F. (2020). Conceptual profile of substance: Representing heterogeneity of thinking in chemistry classrooms. *Science & Education*, *29*(5), 1317-1360.
[14] da Silva Costa, M. B., & dos Santos, B. F. (2022). The conceptual profile of equilibrium and its contributions to the teaching of chemical equilibrium. *Chemistry Education Research and Practice*, *23*(1), 226-239.
[15] Skoog, D. A., Holler, F. J., & Crouch, S. R. (2007). *Instrumental analysis* (Vol. 47). Belmont: Brooks/Cole, Cengage Learning.
[16] Mortimer, E. F., Scott, P., do Amaral, E. M. R., & El-Hani, C. N. (2014). Conceptual profiles: Theoretical-methodological bases of a research program. In *Conceptual Profiles: A Theory of Teaching and Learning Scientific Concepts* (pp. 3-33). Dordrecht: Springer Netherlands.
[17] Aguiar, O., Sevian, H., & El-Hani, C. N. (2018). Teaching about energy: Application of the conceptual profile theory to overcome the encapsulation of school science knowledge. *Science & Education*, *27*, 863-893.
[18] Mortimer, E. F., & Amaral, L. O. F. (2013). Contributions of the Sociocultural Domain to Build a Conceptual Profile Model for Molecule and Molecular Structure. In *Conceptual Profiles: A Theory of Teaching and Learning Scientific Concepts* (pp. 103-114). Dordrecht: Springer Netherlands.
[19] El-Hani, C. N., da Silva-Filho, W. J., & Mortimer, E. F. (2013). The epistemological grounds of the conceptual profile theory. In Conceptual profiles: A theory of teaching and learning scientific concepts (pp. 35-65). Dordrecht: Springer Netherlands.

[20] Aguiar Jr, O. G. (2013). The implications of the conceptual profile in science teaching: an example from a teaching sequence in thermal physics. In *Conceptual Profiles: A theory of teaching and learning Scientific Concepts* (pp. 235-259). Dordrecht: Springer Netherlands.
[21] do Amaral, E. M. R., Mortimer, E. F., & Scott, P. (2013). A Conceptual Profile of Entropy and Spontaneity: Characterising Modes of Thinking and Ways of Speaking in the Classroom. In *Conceptual Profiles: A Theory of Teaching and Learning Scientific Concepts* (pp. 201-234). Dordrecht: Springer Netherlands.
[22] do Amaral, E. M. R., da Silva, J. R. R. T., & Sabino, J. D. (2018). Analysing processes of conceptualization for students in lessons on substance from the emergence of conceptual profile zones. *Chemistry Education Research and Practice*, *19*(4), 1010-1028.
[23] Baltieri, R. S., Bego, A. M., & Cebim, M. A. (2021). Why the covalent bond is such a complex concept: a conceptual profile proposal. *International Journal of Science Education*, *43*(12), 2007-2024.
[24] Solsona, N. R., Izquierdo, M., & De Jong, O. (2003). Exploring the development of students' conceptual profiles of chemical change. *International journal of science education*, *25*(1), 3-12.
[25] Freire, M., Talanquer, V., & Amaral, E. (2019). Conceptual profile of chemistry: a framework for enriching thinking and action in chemistry education. *International journal of science education*, *41*(5), 674-692.
[26] Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust, D. F. (2002). Development and application of a two-tier multiple choice diagnostic instrument to assess high school students' understanding of inorganic chemistry qualitative analysis. *Journal of Research in Science Teaching, 39*(4), 283-301.
[27] Leicester, H. M. (1971). *The historical background of chemistry*. Courier Corporation.
[28] Partington, J. R. (1989). *A short history of chemistry*. Courier Corporation.
[29] Strathern, P. (2000). *Mendeleyev's dream: the quest for the elements*. Macmillan.
[30] Thompson, M. (1999). A natural history of analytical methods. *Analyst*, *124*(7), 991-991.
[31] Karayannis, M. I., & Efstathiou, C. E. (2012). Significant steps in the evolution of analytical chemistry - Is the today's analytical chemistry only chemistry?. *Talanta*, *102*, 7-15.
[32] Margolis, E., & Laurence, S. (2006). Concepts. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Fall 2008 ed.). Retrieved July 24, 2021, from http://plato.stanford.edu/archives/fall2008/entries/concepts/
[33] *Dictionary of Standard Modern Greek*. (n.d.). Centre for the Greek Language. https://www.greek-language.gr/greekLang/modern_greek/tools/lexica/triantafyllides/search.html?lq=%CE%B1%CE%BD%CE%AC%CE%BB%CF%85%CF%83%CE%B7