Constructing a Conceptual Profile Zone: The Example of Chemical Analysis as Everyday Practices

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Abstract

A conceptual profile consists of different zones, which represent distinct ways of thinking about a concept and are applied in different contexts. In this work, a particular way of thinking about the fundamental chemical concept of chemical analysis, the "chemical analysis as everyday practices" zone, is described as an illustrative example of the development of a conceptual profile model of chemical analysis. An inductive–deductive qualitative analysis approach was adopted to analyse data obtained from different genetic domains that were combined in a dialogic way. More specifically, literature on the history and epistemology of the concept (sociocultural domain) as well as on students' alternative conceptions (ontogenetic domain) was examined and data were categorized in terms of how someone perceives chemical analysis. In our case, the way of thinking about chemical analysis "as everyday practices" involves perceptions of simple organoleptic procedures of isolation and separation of stuff and objects, based on the use of senses and on direct observations of mostly explicit properties in order to fulfil daily and professional needs. Such expanded categories of data subsequently served as a coding framework for the analysis of primary data obtained from students' questionnaires (microgenetic domain). Ontological, epistemological and axiological commitments that differentiate this zone from other ways of thinking were detected.

Keywords: *conceptual profile, chemical analysis, ways of thinking*

1. Introduction

Chemical analysis is a fundamental concept in chemistry [1], which deals with the determination of the qualitative and quantitative chemical composition of materials and chemical substances [2]. The literature on students' alternative conceptions and thinking about the concept of chemical analysis is rather insufficient, because research studies mostly emphasize specific components of chemical analysis, such as chemical identity or chemical substance [3, 4, 5, 6, 7, 8, 9]. Additionally, different approaches have been needed to assess students' comprehension of qualitative analysis [10]. A tool which not only assists teachers in recognizing the many ways students think and understand of a concept but also helps students broaden their thinking by incorporating new scientific ideas is the conceptual profile framework [9, 11, 12, 13].
Therefore, the purpose of our research is the development of a conceptual profile model of chemical analysis through the identification of the different ways of thinking related to this concept. In this paper, the construction of the zone related to the way of thinking about "chemical analysis as everyday practices" is presented as an illustration of how a conceptual profile model of chemical analysis has been developed.

2. Theoretical Framework

The conceptual profile framework is based on the assumption that heterogeneity in thinking for a specific concept exists both in the population in general and in a particular person [12,13]. A conceptual profile model consists of different zones, which represent distinct ways of thinking about a concept and they are applied in different contexts [12]. These ways of thinking respectively correspond to particular ways of speaking about the concept [13, 14].
Different modes of thinking about a certain concept result from research on the concept in three different genetic domains, namely the sociocultural, the ontogenetic and the microgenetic domain [12]. Identified modes of thinking are stabilized by one's ontological, epistemological and axiological commitments to their meaning [15].

The concept should be analyzed in a variety of contexts in which it has a meaning [9]. Data should be gathered from many sources, dialogically rather than linearly, which means that all data groups interact with one another at the same time [11].
The following sources may be used: (a1) secondary literature on the history of science, which provides insight into the concept's sociocultural genetic domain, along with obstacles and shifts in the ways of thinking about the concept and how these shifts shaped the thought processes, (a2) research on the concept's epistemology, which is especially helpful for comprehending how the concept's meaning has been attributed, (b) literature on alternative conceptions that incorporates information from classroom teaching and learning, allowing for the examination of the process of thinking about the concept and of knowledge development in daily life (ontogenetic domain); (c) primary data gathered by questionnaires, interviews or video recordings of interactions in a range of settings where the concept makes sense, such as a science classroom, in order to explore both students' alternative ideas (ontogenetic domain) and the micro-processes during interactions in brief periods of time and in certain environments (microgenetic domain) [11, 13, 15].
Conceptual profile models have been proposed for many scientific concepts, such as life [11], thermal physics [16] and energy [14, 17], matter (particle models of matter, atoms, molecules) [11], substance [9, 18], covalent bond [19], chemical reactions [20], equilibrium [13] as well as chemistry in general [21].

3. Methodology

3.1 Data Collection

As far as the sociocultural domain is concerned, secondary historical and epistemological literature was gathered using search engines and databases, such as Web of Science, Google Scholar and Scopus and thoroughly studied. The data set of the sociocultural domain includes some books about history and epistemology of chemistry, Analytical Chemistry textbooks, relevant conference proceedings, dictionaries and research studies on the development of chemical analysis from a historical and epistemological standpoint. We used the same methodology to collect data about the ontogenetic domain. Our literature consists of previous studies on students' alternative conceptions on chemical analysis, on relevant concepts such as chemical identity and substance and on chemistry in general.
In the microgenetic domain, primary data were collected from students' written responses to open-ended questions regarding the process of distinguishing between simple organic compounds such as ethanol, ethanoic acid, 1-propanol, and propanoic acid. From the whole questionnaire, the following questions were related to the method of thinking about chemical analysis as "everyday practices":
1. Which of the information about the materials given to you is important to successfully distinguish between them?
2. Which of the following distinctions of substances is easiest and which is most difficult to make and why?
3. Suggest a way to successfully distinguish between ethanoic acid and 1-propanol.
Students were provided information about these compounds, including their organoleptic, physical and chemical properties, as well as their applications, sources and spectra (^{13}C-NMR, MS). Data was collected from 44 11th grade (16–17 years old) students studying in two Greek public high schools (indicated as school M and school S). Students participated voluntarily in the study which took place during December 2022.

3.2 Data Analysis

An inductive–deductive qualitative analysis approach was adopted to analyse data obtained from different genetic domains that were then combined in a dialogic way [11].
In particular, data from sociocultural and ontogenetic domains were analysed and categorized in terms of how someone perceives chemical analysis. Such expanded categories of data subsequently served as a coding framework for the analysis of primary data obtained from the students' questionnaires (microgenetic domain) in a dialogic way [12]. Participants from school M are referred to as M1, M2, etc., while those from the school S as S1, S2, etc in order to protect their anonymity. To establish the validity of the analysis, the writers of the current paper examined around 20 randomly selected manuscripts and discussed their disagreements until consensus was reached. It should be noted that a conceptual profile model attempts to illustrate potential genetic pathways for a concept's evolution

into many interpretations. Therefore, the construction of the zones of a conceptual profile model involves more than just classifying data extracts. In order to evaluate the respondents' assertions in light of their ontological, epistemological, and axiological commitments—which are frequently difficult to express clearly—a researcher ought to dive further into the claims made by the respondents [11,15]. The questions listed below, which are adapted from a relevant study regarding a conceptual profile model of substance [9], were used to determine ontological, epistemological and axiological commitments:
1. What kind of entities and/or analytical procedures one commits to consider present when thinking about chemical analysis? (ontological question)
2. On what basis one constructs his/her knowledge about the entities and/or analytical procedures considered present when thinking about chemical analysis? (epistemological question)
3. How one evaluates and affectively judges the entities and/or analytical procedures when thinking about chemical analysis? (axiological question)

4. Results and Discussion

The development of the chemical analysis as "everyday practices" zone will be subsequently discussed in light of its ontological, epistemological and axiological commitments, which are summarized in Table 1.

Table 1. Commitments of the chemical analysis as “everyday practices” zone.

Zone	Commitments
Everyday practices	- Ontological: materials are complex entities – categories of stuff that can separated into their basic parts with simple procedures of isolation and separation involving the use of human senses - Epistemological: explicit properties of entities, direct observation - use of senses, independently of theoretical ideas, not necessarily in a laboratory - Axiological: useful entities and processes for daily and professional needs, simple, easy, not so valid or reliable

4.1 Ontological Commitment

Historical and epistemological literature mostly discussing the pre-alchemical era [22, 23] suggests that since the beginning chemistry has primarily connected with analysis [24]. This initial type of analysis, which surely predated both alchemy and chemistry [25], is often referred to as "art" [26, 27] or *"ars probandi"* (art of assaying) [28]. The main idea behind chemical analysis originated with the related philosophical perspective, which, influenced by Aristotle's analysis of causation, compares chemical analysis to philosophical analysis in the context of separating what is more basic from what is more complex using any method [29]. Basic analytical techniques, mostly employing human senses, such as isolation and separation, were involved in perceiving chemical analysis as such a straightforward process [23]. By posing the ontological question, we argue that, from a sociocultural perspective, the ontological commitment for this mode of thinking includes views of complex matter that can be separated into its basic parts with simple processes of isolation and separation using human senses.
In the ontogenetic domain, it is suggested that the complex matter indicated by the sociocultural domain is frequently perceived by young students as separate classes of stuff, which are unique and different from one another [9]. Students' tendency to view materials as objects *("objectivization")* with characteristics mostly ascribed to objects (size, shape, etc.) is another intriguing discovery. This tendency definitely influences their thinking in tasks dealing with separation and isolation of matter [7, 30, 31]. According to this viewpoint, the ontological commitment is broadened by including the above mentioned perceptions about entities that are considered present during analysis. Thus, people who view chemical analysis "as everyday practices" are ontologically devoted to the idea that complex matter is classified into categories or types of stuff and objects and simple procedures of isolating and separating of complex matter into its basic parts involve the use of human senses.
These claims are supported by microgenetic domain results. The most common responses involved basic organoleptic procedures of isolation and separation, such as *"… we first <u>taste</u> or <u>smell</u> it…"* (M1), *"… we can distinguish the substances <u>directly</u>…"* (M4), *"Initially, I would check its <u>clarity</u>…"* (M9), *"… I <u>taste</u> a sample…"* (M24). According to another response (student M20), *“… the information I have chosen is that which, through certain processes, can <u>remove substances from the mixture</u> or reveal their existence…”*. This viewpoint is related to the core idea of analysis mentioned before, which is the

separation of what is more basic from what is more complex. Furthermore, some respondents see materials as distinct classes of stuff. Student M8 commented: *"… knowing which category they belong to allows for differentiation…"*. We could not find any thoughts about objectivization in the responses, thus, even if such notions have been reported in the relevant literature in the ontogenetic domain, we do not include them in the ontological commitment.
Therefore, considering data from all three genetic domains in a dialogic way, as described above, the ontological commitment of the zone of chemical analysis as "everyday practices" includes thinking about materials as complex entities or categories of stuff that can separated into their basic parts with simple procedures of isolation and separation involving the use of human senses.

4.2 Epistemological Commitment

In the sociocultural domain, basic organoleptic processes were unquestionably founded on observation alone, employing the use of human senses [22, 26, 32]. Procedures evolved independently of theoretical concepts and instinct, skills, practice and experience were all crucial. Analytical procedures were verbally transmitted from generation to generation and were not always carried out in a designated, structured area (such as a laboratory) or documented [22]. Materials were only described and characterized by their colour, weight, solubility, temperature, density, hardness, appearance, brightness and humidity without using the scientific terminology that we use today [22]. Subsequently, answering the epistemological question, in the sociocultural domain knowledge about chemical analysis is constructed via firsthand observation of materials through the employment of the senses (smelling, seeing, touching, etc.), not necessarily in a laboratory and without reference to theoretical concepts. Furthermore, instinct, talent, practice, and experience seem to be really crucial.
The ontogenetic domain's findings stabilize the epistemological commitment that was first identified through the sociocultural domain's data analysis. To be more precise, a significant portion of the data regarding students' alternative views of chemical analysis also highlights the importance of using the senses. Chemical identity decisions made by novice learners are impacted by surface similarity, perceptual and macroscopic features and appearance [6, 7, 31]. Smell, taste, colour, weight, volume, texture, shape, hardness and tangibility are among the most common explicit attributes they use that are detectable by the senses [4, 8, 9]. Also, when attempting to separate matter, learners frequently place a lot of attention on attributes that are primarily linked to objects (such as size, form, mass, weight, softness, thinness, brightness, etc.) [5, 7, 30, 31]. Students' assumptions that surface similarity and object-related properties may be evidence of the inner structure of materials are strong cognitive barriers [7] because their thinking about chemical analysis may be limited to the recognition of these obvious traits. We propose that, incorporating ontogenetic domain's data, the epistemological commitment of this way of thinking states that knowledge about chemical analysis "as everyday practices" is constructed through direct observation of materials, with emphasis on their explicit or object-related properties, using the senses (smelling, seeing, touching, etc.), and independently of theoretical ideas.
Examining the microgenetic domain, in many responses the following properties were mentioned: *odour, taste, colour, appearance – form and clarity*, which students perceive through the processes of *smell, taste* and *seeing* respectively. Student M24 mentions characteristically: *"… The colour and odour immediately reveal the existence of the chemical, as does the taste, after consumption…"*. Several students emphasize the use of the senses and direct observation, as seen by the following responses: *"...I chose the features that are distinct to the human senses..."* (M9), *"...they can be observed with the naked eye or without experiments..."* (M7). Combined with participant M7's words *"without experiments"*, the comments of two more participants: *"... first to distinguish the substances in the most obvious way (colour, taste, smell) in everyday life ... and then to confirm in another way in the laboratory..."* (M12, M21) support the sociocultural finding that chemical analysis is not always carried out through experiments in an organized setting such as a lab. Furthermore, one student (S3) states that such procedures can be carried out by *"...someone who does not know chemistry … using just these simple words, namely the characteristics..."*, which accords with the fact that analysis of that kind is carried out regardless of theoretical notions. It is worth noting that no features linking directly to objects (ontogenetic domain) or implying ideas about instinct, skill, talent and experience (sociocultural domain) were detected.
As a result, the epistemological commitment of this zone has been refined through analysis of findings from all three genetic domains in a dialogic way. When considering chemical analysis as an everyday practice, the basis on which people construct their knowledge about the entities (complex matter) and analytical procedures (simple, organoleptic) is direct observation and use of senses (smelling, seeing,

etc.) so as to perceive the explicit properties of materials, independently of theoretical ideas and not necessarily in a laboratory.

4.3 Axiological Commitment

According to the history and epistemology of that period, the application and results of chemical analysis were far more significant than the method itself. The main objectives of analysis were to meet everyday and professional needs related to ceramics and metals, such as gold and silver [22, 23, 33, 34], cosmetics, soaps, leather, fabrics [35] and natural pigments [26, 34]. From the viewpoint of the sociocultural domain, this is associated with the axiological commitment that, in order to meet their everyday and professional demands, people analyze only the entities and use only the analytical processes that they feel advantageous, such as those concerning metallurgy or cosmetics.
Data from the ontogenetic domain shed additional light on the evaluation of the entities under consideration in this zone. Learners frequently judge a material by its source or typical habitat, purpose or function while determining the material's chemical identity and whether it has changed [8]. In many cases, children consider valuable behaviors or functions that may indicate that an object belongs to a larger category, such as edible materials, construction materials, art materials, cleaning materials, etc. Especially for younger children, students' criteria are restricted to simple useful actions or changes (e.g., it makes sound or it is flexible). In addition, the similarity with popular exemplars of materials widely utilized in our daily lives, such as clay, plasticene, glue, sugar, iron and wood, is frequently the only judgment learners make regarding a material's identity [4, 5]. Hence, the axiological commitment is enriched in its component of the object of analysis, namely the evaluations and judgments about the entities that individuals find helpful in their daily and professional life and, thus, analyze. Specifically, a material's utility lies in its origin, habitat, purpose and function as well as its similarity with useful exemplar materials.
Our findings in the microgenetic domain support and enhance the evaluations in terms of both the entities and the analytic procedures. Students responses to questions include the following: *"… I'd like to know if these materials are part of a <u>food or other products that we use on a daily basis</u>…"* (M8), *"… information on where each substance is <u>used in everyday products</u>…"* (M3, M25), *"… in <u>which foods or products</u> it is an ingredient…"* (M9). These ideas support our argument about evaluating the utility of the entities analyzed and the procedures employed. Furthermore, we identified some more assessment and judgments about the analytical processes as they are viewed in this zone: on the one hand they are *"simple"* (S11, S19) and *"easy"* (S14, S18, S19) but on the other hand they are *"not so valid"* (M19) and *"not so reliable"* (M13).
Therefore, considering data from all three genetic domains in a dialogic way, as described above, the axiological commitment of the zone of chemical analysis as "everyday practices" is as follows: individuals analyze only the entities that they find useful in their daily and professional lives and this utility lies in the material's origin, habitat, purpose, function and similarity to valuable exemplar materials. Also, they employ only the analytical processes they believe to be beneficial, such as those involving food, metallurgy, cosmetics, etc., which are evaluated as simple and easy yet not so valid or reliable.

5. Conclusions

The purpose of this study was the illustration of the development of a zone of a conceptual profile model of chemical analysis, namely the way of thinking about "chemical analysis as everyday practices". It is important to clarify that neither details on the development of the questionnaire nor results pertaining to the participants are discussed in this work (e.g., what were the dominant ways of thinking about chemical analysis, differences among students of different schools, etc.).
Our conclusions regard the commitments involved in considering chemical analysis "as everyday practices". To be more precise, in terms of the ontological commitment, thinking about chemical analysis as everyday practices entails viewing materials as complex entities and/or categories of stuff that can separated into their basic parts with simple procedures of isolation and separation involving the use of human senses. Regarding the epistemological commitment, knowledge about chemical analysis as everyday practices is built by direct observation of their explicit properties with the use of senses (seeing, smelling, etc.), independently of theoretical concepts and not necessarily in an organized setting such as a laboratory. Finally, the axiological commitment is founded on the belief that individuals should only analyze useful materials and employ methods that they view as valuable

for covering their everyday and professional needs such as food, which are also characterized as simple and easy, yet not so valid or reliable.
In a later stage of research, the remaining zones will be established and a conceptual profile model for chemical analysis will be proposed [9, 11, 13, 15].

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