PROSPECTIVE PHYSICS-CHEMISTRY SECONDARY TEACHERS' KNOWLEDGE OF THE DIFFERENT LEVELS OF REPRESENTATION IN CHEMISTRY

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ABSTRACT

Chemistry concepts are described at macroscopic, sub-microscopic and symbolic levels. This paper aims to evaluate the prospective physics-chemistry secondary teachers' (PPCTs) knowledge of the multiple levels of representation in chemistry. A quantitative study using a cross-sectional test was conducted on forty-eight participants. Results show higher trainee achievement at the macroscopic level. The order of acquisitions remained very similar for definitions and examples (Macro > Sub-Micro > Symbolic). Both chemistry (6.67%) and physics (6.45%) license graduates have scored close percentages to define the symbolic level. PPCTs are suffering conceptual difficulties to give examples illustrating each level of representation in chemistry. The highest level of knowledge concretization is in favour to chemistry license. Females perform three times more than males at the macroscopic level. PPCT performances increase with post-license training. *[African Journal of Chemical Education—AJCE 14(3), July 2024]*

INTRODUCTION

Traditionally called macroscopic, sub-microscopic and symbolic, the levels of representation in chemistry are used to explain, predict, and change the chemical phenomena [1, 2]. They play an essential role to improve students' chemical knowledge, and consequently to enhance the quality of chemical education. The development of students' understanding of the chemical events is based on abilities to explain concepts at each level of representation and to make relation between them [3-7]. A formal link involving reasoning about chemistry concepts and coordination between three types of knowledge forming a triplet relationship [8], leads to multilevel thought [9], and contribute to the mastery of teaching and learning process. However, different levels of teachers' content knowledge have been reported. A comparative study of three teachers' pedagogical knowledge related to the triplet relationship that affects directly their teaching attitudes was carried out [10]. The first possessing weaker level of knowledge than others, believes that it is adequate to connect any two levels of triplet relationship, but it is not necessary to teach it very explicitly. The second having good pedagogical knowledge of triplet relationship, adopts a teaching strategy based on the use of macroscopic level as the core, which is completed by sub-microscopic explanation and symbolic representation. The third teacher possessing very good pedagogical knowledge of triplet relationship thinks that the most important challenge is the choice of the right context to teach the triplet. Widarti [11] reports that 49.33% of a simple including seventy-five chemistry teachers in Indonesia do not know multiple representations in chemistry. Teachers who understand them use frequently macroscopic and symbolic representations in chemistry learning rather than submicroscopic. Furthermore, the mobilization of levels of representation in chemistry teaching depends on the teacher priority [12]. Thus, teachers using more macroscopic concepts use fewer concepts describing microscopic and symbolic levels; teachers favoring microscopic concepts use more concepts from symbolic level. Moreover, Mindayula and Sutrisno [13], basing on descriptive qualitative study included six participants, show that chemistry teachers are not familiar with the concept of multiple representations. In classrooms, pre-service chemistry teachers' had difficulties to integrate multiple levels of representation with the contents [14]. Another study indicates that most of pre-service science teachers are not able to mobilize macroscopic, symbolic, and sub-microscopic levels in order to describe the substances when it is dissolved in water [15]. Likewise, Talanquer [16] has highlighted the prospective teachers' inability to criticize the existence of three levels of representation. On the other hand, the understanding of the levels of representation is also challenging for learners, constituting a source of difficulty [9]. Literature suggests that the development of a robust understanding of foundational chemistry concepts requires student abilities to relate their knowledge's in the symbolic mode to the macroscopic and sub-microscopic levels [4, 8, 17-21]. Students often fail to integrate these levels during the learning process because of their fragmented understanding [22].

For both student and teacher, two main factors are predicated as contributing aspects of difficulties in understanding levels of representation in chemistry. Firstly, problems to explain clearly the levels of representations in chemistry; and secondly the capacity to move between the three levels [22]. According to the aforementioned context, it has been highlighted teachers' obstacles to mobilize levels of representation in chemistry teaching. Thus, the question of the prospective physics-chemistry secondary teacher (PPCT) knowledges of the different levels of representation in chemistry represents an angular point around which the student's knowledge can be built. PPCTs, as future teachers, constitute potential sources of difficulties in chemical education. This paper stipulates to discover the secondary PPCTs' knowledge of multiple representations in chemistry.

Conceptual Framework

Levels of representation in chemistry constitute the main tools for student to formulate there proper interpretation of matter and its transformations. They have been described to explain the abstractness of education chemistry phenomena.

Based on life experience, the macroscopic level addressing visible, is mostly studied in chemistry learning. It's related to observable phenomena [23] which are large enough to be seen with the naked eye, touched, and felt [24, 25]. In addition, this level based on human senses describes the things we can measure with basic instruments. At this level, to define concepts, teachers mobilize every day experiences [14] and chemical reactions observed by experiments. Otherwise, the macroscopic level constitutes a basic reference for learners to understand the chemical concepts at other levels of representation [26, 27]. These perceptible properties are generated as a result of collective interactions between atoms or molecules at the particle or molecular level of the substance. The macroscopic level is based on practical demonstrations or real world examples to introduce chemistry topics [28]. Teaching this level of representation helps learners to relate concepts being presented in classroom to their own experience [28]. Two ways can be employed to accomplish this aim. First, the teacher gave a clear explanation of chemistry through something familiar and performs demonstrations, and then helps students to discuss the observed phenomena [28]. The microscopic level of representation, sometimes called sub-microscopic, atomic, particulate, molecular level, illustrates the scale of real entities but too small to be observed [3]. All things not perceive with our senses are described in this level. It often serves to explain the matter in terms of the movement of particles. At this level, teachers visualize chemical representation using entities such as electrons, atoms, ions, and molecules in chemical reactions [29]. To represent these entities, the particulate level is often taught using two-dimensional drawings of dots and circles in order to guide students to a visual understanding of chemical phenomena [28]. This level of representation occupies a vital position because chemical explanations almost always depend on the sub-micro level [30]. The particle level is the most valuable level for chemists. Reason why these latter usually rely on other technologies to extend their senses, in order to understand and study the smallest constituents. The third level, as known under the symbolic representation, is applicable to communicate about chemical phenomena in order to describe chemical symbols, properties, phases, and chemical reaction equations. Representations explored in this level are based on symbolic tools such as pictorial, algebraic, physics equations, graphs, reaction mechanisms, analogies and model kits [3, 16]. These are useful in teaching and learning chemistry [31]. In this case, students could solve problems using their symbolization ability, but does not necessarily justify an understanding of the underlying chemistry concepts.

The macroscopic level at which students have the most experience in everyday life is most familiar. Between all levels of multiple representations, no superiority exists, but each one complements another in order to illustrate the chemical concepts [32]. Thus, the possibility to connect from one level of representation to another is therefore needed [33]. In teaching chemistry, simultaneous utilization of representative levels reduces leaners' misconceptions [34]. For better conceptual understanding, all topics of chemistry can be taught at these levels of representation.

Two reasons explain the search relevance. Firstly, studies on multiple representations in chemistry have only focused on student challenges, but not on teachers who did not attract a particular attention [13]. Their importance in chemistry explains researcher's interests to know learner levels of representation [35], suggesting an enrichment set in this area for scientist community. Secondly, the development of teachers in chemistry subjects such as levels of representation positively affects students' learning and success.

Purpose and Research Questions

The purpose is focalised on PPCT achievement test inducing knowledge's related to the levels three of representation in chemistry. Research study intends to answer the following questions: how PPCT define macroscopic, sub-microscopic and symbolic levels of representation in chemistry? Are PPCT able to support their responses for each case using examples? How PPCTs knowledge about different levels of representation changes according to the field of teaching, gender and degree?

METHODOLOGY AND PROCEDURES

Research design and procedure

Research aims to quantify PPCTs acquisitions related to three levels of representations in chemistry learning. The study starts with the formulation of a research problem based on the knowledge literature evaluation, and plan for achieving objectives. The next step envisages data collection to obtain information required to answer the research issue. An achievement test was chosen as the main tool to collect information. Participants were invited to complete, according to the cross-sectional design, the items during outside-school hours. The test was carried out in face-to-face via a paper and pencil form, leading to achieve high quality data [36]. Respondents were not permitted to use any support documents. They can refuse to answer any item or withdraw from participation. Also, they were not informed on the test subject, and have no opportunity to prepare. No explanations have been given.

Sample

Participants to this research included forty-eight (48) PPCT volunteers aged from 22 to 29 years. There were more male (56.25%; 27) than female (43.75%; 21) training respondents. They graduate with license (bachelor) diploma in the fields of study of chemistry (31.25%) and physics (68.75%) undertaken at least three years of university studies. No participant comes from education and teaching training area. Also, the sample includes participants who have got a master's degree (60.41%). All respondents have successfully passed a competitive regional physics-chemistry teacher recruitment organized by the Eastern regional academy of education and training (Morocco, 2022). After the final selection procedures designed to choose the best candidates, those admitted follow qualifying training programs (2021/22) in order to develop and improve practical and professional skills, and to update their academic knowledge's [37-39]. Thus, during their teaching training, PPCTs have opportunities to exploit the triplet knowledge representation in chemistry courses [40, 41]. Successful PPCTs are awarded the certificate of competence in education required later to gain qualified teacher status [39].

Materials and instrument

The research test consists mainly of open-ended questions which allow PPCTs to create responses within their experiences instead of the researcher's experiences [42, 43]. PPCTs provide their own responses to questions, and supply answers. The instrument was produced in three stages. The first one involves curriculum analysis in order to identify the levels of representations employed in Moroccan secondary chemistry education [40, 41]. The second stage focuses on the development of an achievement test involving six questions divided into two blocks created and validated as follows. The input block envisages the *meaning* of studied concepts: macroscopic (Q1-1), sub-microscopic (Q1-2) and symbolic (Q1-3). The output part targets gathering participant examples related to each level of representation (Q2-1, Q2-2, Q2-3). Two secondary school teachers using levels of representation in chemistry education, and two university experts were asked to evaluate the instrument. Whether the items can actually access to the investigated topic and their validity to measure the PPCT acquisitions of levels of representation in chemistry were commented. The third stage consists on pilot testing of the initial test version [42]. Ten (10) PPCTs, which are enrolled in the first year of qualifying training at the Eastern regional center of education and training jobs (Morocco) during the year 2020/21, are invited to complete the instrument and to give items comments. Based on the participant feedback a revised test has been produced, and the time requirement to complete it has been estimated at fifteen (15) minutes. The test having undergone minor modifications was finally presented to the sample. High test completion rate (93.75%) has been obtained.

Data collection and analysis

This study integrates a descriptive quantitative research method using a test to answer research questions [42, 44]. After collecting and preparing data for analysis, the sentences formulated on the open-ended responses involve setting up categories and their transformation into quantitative results, according to three steps [42]. Firstly, the responses were categorized into three groups (True, False, Non Response (NR)) leading to transform them into numbers. One PPCT defines macroscopic level in Q1-1 as "everything that can be seen with the naked eye". For the same question, another participant links this level with molecular representation "macroscopic level represents the molecular structural level". Statistical quantities such as frequency (f), percentage (%), correlation coefficient (r), standard deviation (SD), *p* and *F*-values were computed using Microsoft excel 2010 software program and the online scientific calculator [45]. Secondly, the bivariate analysis is conducted taking into account initial training, gender and post-license training. Comparisons were carried out using the above statistical variables. The third step includes the validity and reliability of research measurement. Thus, information's were analysed independently by two researchers and discussed within our laboratory group. A consensus was reached on the final data.

RESULTS AND DISCUSSION

PPCTs' knowledge of levels of representation in chemistry has been investigated. The paper plans to identify among participants the meaning of three concepts (macroscopic, sub-microscopic, symbolic) trough mobilizing examples of chemistry.

Global results

The data presented in Table 1 show a high non-response rate (90%). Some PPCT participants have unregistered their personal data and submit the test, but they did not answer research items.

TABLE 1: Percentages (%) of obtained answers

Items	Levels	True	False	NR
Q1-1	Macro	22.22	2.22	75.56
Q1-2	Sub-Micro	11.11	4.44	84.44
Q1-3	Symbolic	6.67	0.00	93.33
Q2-1	Macro	6.67	0.00	93.33
Q2-2	Sub-Micro	4.44	0.00	95.56
Q2-3	Symbolic	2.22	0.00	97.78
Overall mean		8.89	1.11	90.00

The first block of questions, which were answered by the 2021/22 cohort, is more challenging than the second. Low true response rates have been scored for each item varying between the greatest value (22.22%, Q1-1) and the smallest value (2.22%, Q2-3). Thus, most of the PPCTs failed to satisfactorily define the studied terms and did not know the concept of multiple representations in chemistry. These findings are in good agreement with the literature, as it was previously noted that chemistry teachers could apply macroscopic and symbolic levels of representation in chemistry teaching, but they have no academic knowledge's [11], and they were not familiar with the terms or definitions of the three different levels of representation [13]. From research participants only 10%

of answers have been collected. The above data shows that the level of PPCTs, especially in the case of the second block, is considered flawed. The true definitions formulated by respondents for levels of representation vary in the following order: Macro (22.22%) > Sub-Micro (11.11%) > Symbolic (6.67%). Similarly, to check if trainees are able to give examples that relate three concepts to the real world that can take multiple forms from chemistry area, responses provided for each case show identical classification with lower percentages: Macro (6.67%) > Sub-Micro (4.44%) > Symbolic (2.22%). As revealed by the participant responses collected in both blocks, the macroscopic level is the most mastered among PPCTs. Based on the six questions, the low mastery of the learners among the PPCT chemistry competencies are on defining the symbolic level (6.67%) and focusing knowledge's using examples (2.22%). Answers analysis indicates that PPCTs share the biggest obstacles to give examples. Thus, uses of chemistry examples in the real world are an index of mastery of the levels of representation among participants.

Possible reasons for the low true response rate, relate probably the challenges of studied subject mastery, including the lack of interest in the levels of representations in chemistry, poor retention and conceptual understanding, insufficient prior knowledge about the topic, lack or poor in-depth discussions by the teacher, and poor consolidation of knowledge between the trainees [46].

Also, factors such as curricular academic activities, teaching approaches, students' competence and aptitude and learning facilities and technology can explain participant results [47].

Performance comparison in term of initial training course

Being able to explain chemical concepts involving levels of representation requires applying scholarly knowledge acquired during the process of learning. The effect of initial training course on trainee outcomes has been examined (Table 2).

TABLE 2. Results related to the field of study

Type of license		Chemitry			Physics		
Items	Levels	True	False	NR	True	False	NR
Q1-1	Macro	26.67	6.67	66.67	22.58	0.00	77.42
Q1-2	Sub-Micro	6.67	13.33	80.00	12.90	0.00	87.10
Q1-3	Symbolic	6.67	0.00	93.33	6.45	0.00	93.55
Q2-1	Macro	20.00	0.00	80.00	3.23	0.00	96.77
Q2-2	Sub-Micro	13.33	0.00	86.67	0.00	0.00	100.00
Q2-3	Symbolic	6.67	0.00	93.33	0.00	0.00	100.00
Overall mean		13.33	3.33	83.33	7.53	0.00	92.47
SD		8.433	5.578	10.111	8.815	0.000	8.815
R		--	--	--	0.521	--	0.821
F-value		--	--	--	1.361	2.144	2.787
p-value		--	--	--	0.271	0.174	0.126
Level of significance at $p < 0.05$					No	No	No

Indeed, participants from physics fields perform better at the particular level of representation. They score higher percentage at sub-microscopic representation (12.90%) compared to their colleagues possessing license degree in chemistry area (6.67%). For both training courses, definitions formulated for the macroscopic representation have scored fairly close results (chemistry: 26.67%; physics: 22.58%). For the other items, the knowledge concretization is in favor to chemistry profile. These last PPCTs exploit better examples in chemistry, contrary to physics participants who failed to give reel situations of even at sub-microscopic level.

On the other hand, overall percentages of true answer presenting identical SD, using as the most common measure of dispersion [48], are more pronounced for chemist trainees (13.33%) than physics participants (7.53%). This result shows that levels of representation in chemistry are most challenging for PPCTs with physical profile. Moreover, the correlation coefficient value of 0.521 indicates that true results scored by chemistry and physics PPCTs are moderately and positively correlated [48, 49]. Finally, the F-test employed in statistical analysis data set to determine the model with the best fit [50] gives the F-value of 1.361 justifying that the variance of true response populations is not significant at $p < 0.05$.

Effect of gender on the response rates

At looking the gender variable many particularities have been recorded (Table 3). Indeed, male PPCTs were significantly different from female respondents in whether they were likely to complete the test research. Females were more motivated to respond to test items [51]. Test completion and true response rates among males and females were tested, and the differences were statistically analyzed. In fact, the total response rate among the females (17.54%) is higher than that obtained by males (4.49). Additionally, the average true response percentage obtained by females (14.91%) is longer than this scored by the opposite gender (4.49%).

At the macroscopic level, females (36.84%) perform three times more than male PPCTs (11.54%). Also, the score of female participants (15.79%) is higher than males (7.69%) at sub-micro level of representation [52]. However, an opposite result was obtained at the symbolic level where males (7.69%) score higher true responses than females (5.26%). Salient results have been obtained in the second block case. All male participants were unable to give examples that illustrate the three levels of representation in chemistry contrary to the females for which the values range between 15.79% and 5.26%.

TABLE 3. Comparison of responses in term of gender

Gender		Male			Female		
Items	Levels	True	False	NR	True	False	NR
Q1-1	Macro	11.54	0.00	88.46	36.84	5.26	57.89
Q1-2	Sub-Micro	7.69	0.00	92.31	15.79	10.53	73.68
Q1-3	Symbolic	7.69	0.00	92.31	5.26	0.00	94.74
Q2-1	Macro	0.00	0.00	100.00	15.79	0.00	84.21
Q2-2	Sub-Micro	0.00	0.00	100.00	10.53	0.00	89.47
Q2-3	Symbolic	0.00	0.00	100.00	5.26	0.00	94.74
Overall mean		4.49	0.00	95.51	14.91	2.63	82.46
SD		5.112	0.000	5.112	11.729	4.403	14.382
r		--	--	--	0.619	--	0.698
F-value		--	--	--	3.983	2.142	4.390
p-value		--	--	--	0.074	0.174	0.063
Level of significance at $p < 0.10$					Yes	No	Yes

Furthermore, male respondents did not manage to give any incorrect answers. The order of true answers recorded for females is identical for both definitions and examples: Macro > Sub-Micro > Symbolic. Also, females were more efficient to illustrate the meaning of three concepts, but their difficulties are much highlighted when it comes providing examples. Moderate correlation (0.619) between male and female true responses has been obtained [48, 49]. The SD quantity [48] is greater than the mean scored by males, and less than the mean scored by females. Hence, low SD relative to the average indicates that female test scores are clustered tightly around the mean [53]. Let's now analyze the F-value and p-value showing statistically significant difference between male and female true responses at $p < 0.10$. To close, female achievements are significantly higher than males across two blocks at all levels of representations, expect for the symbolic definition that showed an achievement male scores higher than females. This divergence according to gender can be linked to the gap between skilled and unskilled use of explanative examples.

Post-license training versus PPCT acquisitions

In this sub-section, we focus on the relationship between the understanding of multiple levels of representation in chemistry and participant post-license diplomas. Results show the influence of this variable on the scored values (Table 4).

Indeed, the rate of true answers is very visible for trainees who have undergone training after their license degree (13.33%) compared to respondents that have just license diploma (2.08%). In fine, changes vary between 33.33% (Q1-1) and 3.3% (Q2-3). The total response rate obtained by post-license PPCTs (15.00%) is higher than that scored by participants who graduated with bachelor's degree (2.08%).

TABLE 4. Influence of post-license training on the acquisition

Post-liense training		With			Without		
Items	Levels	True	False	NR	True	False	NR
Q1-1	Macro	33.33	3.33	63.33	6.25	0.00	93.75
Q1-2	Sub-Micro	16.67	6.67	76.67	0.00	0.00	100
Q1-3	Symbolic	10.00	0.00	90.00	0.00	0.00	100
Q2-1	Macro	10.00	0.00	90.00	6.25	0.00	93.75
Q2-2	Sub-Micro	6.67	0.00	93.33	0.00	0.00	100
Q2-3	Symbolic	3.33	0.00	96.67	0.00	0.00	100
Overall mean		13.33	1.67	85.00	2.08	0.00	97.92
SD		10.750	2.789	12.605	3.227	0.000	3.227
R		--	--	--	0.601	--	0.512
F-value		--	--	--	6.029	2.142	5.912
p-value		--	--	--	0.034	0.174	0.0354
Level of significance at $p < 0.05$					Yes	No	Yes

Another major result shows that PPCTs having followed post-license training had higher scores (33.33%) than bachelor's students (6.25%) at the macroscopic level. Furthermore, as regards either defining three levels of representation or giving examples, the orders of true percentage answers are unchanged compared with those obtained in global results (Macro > Sub-Micro > Symbolic). The correlation coefficient value (0.601) between two populations indicates a moderate positive linear relationship [48, 49]. Comparison between the overall mean and SD shows opposite resultants. The SD (10.750) is smaller than the mean (13.33) for participants with post-license training, while the SD (3.227) is greater than the mean (2.08) for the second group. For this last group, a high standard deviation compared to the average indicates that scores of participants without post-license training are more spread out. Analysis of both *F*-value and p-value shows significant difference between two group responses at $p < 0.05$. Consequently, future teacher acquisitions of levels of representation in chemistry are controlled by the nature of the university degree. For all chemistry representations, the postgraduate PPCTs achieved better performances than undergraduates. From where, trainees graduating with license's degree are less efficient than their colleges which have triggered training for research. Compared to participants who have undergone post-graduate training, PPCTs at the license degree have more obstacles in the field of representation in chemistry. To sum, the post-license training influences largely the PPCT knowledges. This may increase measured teacher value-added. Factors that can explain this low performance are probably the lack of chemical culture, the deficiencies concerning the training curricula, the teaching-learning process, and the experimental materials.

CONCLUSION AND IMPLICATIONS

This research, involving descriptive quantitative method, aims to evaluate PPCTs' knowledge referring to three levels of representations in chemistry named macroscopic, sub-microscopic and symbolic. Mobilization of scientific definitions and examples founded the research questions. Therefore, the study examines the PPCTs knowledge about different levels of representation, and to make distinction in that knowledge based on the field of teaching, gender and degree. Four key findings framing this research rely on studied sample. Firstly, PPCTs perform better at the macroscopic level of representation. As far as definitions or examples answers, the order of acquisitions of levels of representation remained very similar for two blocks (Macro > Sub-Micro > Symbolic). However, examples answer justifications in the real world as an index of mastery of the levels of representation are challenging for all participants. Curricular academic activities, teaching approaches, students' competence and aptitude, and learning facilities and technology can explain probably the low responses performances. The second outcome, for both chemistry and physics license degrees, it is notable that all definitions given for the symbolic representation have scored fairly close results. Knowledge trainees' concretizations are in favour to chemistry profile. Another salient finding shows that the male performances fell. Thus, female PPCTs perform three times more than male PPCTs at the macroscopic level. They were more efficient to define studied concepts, but their difficulties are much highlighted when it comes to providing examples. Our last finding demonstrates that PPCTs who have been completed postgraduate training had higher scores than bachelor's participant at the macroscopic level. Also, all PPCT acquisitions are controlled by the nature of the university degree. It appears that postgraduate PPCTs achieved better performances than undergraduates.

Levels of representation in chemistry occupy a large portion in many teaching chemistry disciplines. The test findings allow us to draw relevant perspective projects. Future researches are asked to examine the effect of didactic interventions on the orientation of learners' performances according to the levels of representation. Also, interactions between chemistry areas and PPCTs acquisitions of levels of representation in chemistry are promising investigation axis.

The present study reveals implications for 21st century teacher education regarding the knowledge and skills of PPCTs related to multiple levels of representation in chemistry and so that the potential of students in chemistry classrooms can be enhanced. The development of innovative curriculums and textbooks can encourage prospective teachers to orient their basic acquisitions towards the mastery of macroscopic, sub-microscopic and symbolic levels of representation. Also, educational means, methods and materials mobilized during the initial and qualifying trainings are likely key elements to improve prospective teacher acquisitions of levels of representation in chemistry. Furthermore, the use of acquired knowledge in teaching process results learners' skills enhancement. Finally, the access to upper secondary teacher training program is currently open to candidates holding a licence diploma. Therefore, the revision of entry requirements requires update raised still further, limiting admission to holders of post-license graduates.

DISCLOSURE STATEMENT

The author declares no conflicts of interest.

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