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The influence of affective analogies on students' affect for chemistry learning and attitudes

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ABSTRACT
Educators cannot overlook the affect's potential for students' educational success. In this study, affective analogies are proposed as a didactic resource to foster students' affect for chemistry learning and positive attitudes towards the physics-chemistry subject. To examine the influence of the affective analogies on it, we grouped contents of this subject into three modules (Kinetic-molecular theory; Quantum model of the atom; Chemical elements and their isotopes) and developed analogies between chemistry and music for each (affective analogies), which were then compared to homologous undifferentiated analogies (familiar analogues without affective qualities in addition) and teaching strategies without analogies. An explanatory mixed-method design was used. Data were collected through questionnaires and interviews, with a convenience sample of 147 students attending the 7th grade of a middle school music course. The results show that the affective dimension of analogies promotes positive affect for learning at much higher levels than the familiar dimension. We proposed a mechanism through which this occurs. However, if analogies are familiar, it seems that their positive affective dimension is not as important for students' learning levels. More than interesting, analogies should perhaps be non-aversive. As for attitudes towards physics-chemistry, teaching with affective analogies is the most beneficial strategy. This results from students' perception that this teaching approach promoted positive affect for the study of physics-chemistry, compared to undifferentiated analogies and without analogies. Furthermore, it favoured learning and achievement in physics-chemistry, compared to the absence of analogies, because without analogies it is more difficult to understand abstract or difficult concepts.

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Introduction

Psychologists and neuroscientists believe the affective domain enhances students' educational success (Damásio, 2006; Goleman, 2020; Jensen & McConchie, 2020). Howard Gardner said to Daniel Goleman: "You learn at your best when you have something you care about and you can get pleasure from being engaged in" (Goleman, 2020, p.84). As current society becomes increasingly shaped by scientific and technological knowledge, science literacy becomes a fundamental skill for any citizen.

Once again, the affective dimension of learning is recognized as important. Students' current and future engagement with science is primarily correlated with their attitudes towards science and science-related activities, as well as their self-concept in science. Behind this engagement are also students' interest and motivation to learn science (OECD, 2016). Given the recognized importance of the affective dimension for students' educational success, it is crucial to develop pedagogical dynamics and didactic applications that are based on and give rise to affect for learning. A target context could be the teaching and learning of chemistry in the subject of physics-chemistry. We believe that the use of students' familiar and affective knowledge through analogies may be a way to do it. However, in practice, how will the affective dimension and familiarity of analogies benefit students' affect for learning and their attitudes towards the subject of physics-chemistry? This is the main research question of this study. Physics-chemistry (PC) is a compulsory subject for Portuguese middle school students attending the 7^{th} to 9^{th} grades. For each grade level, the teacher remains the same throughout the school year, teaching both scientific areas within this subject. During a part of the year teaches physics and in the other chemistry. In middle school national curriculum there are no independent physics and chemistry subjects. We chose to focus our research on PC subject since students consider it the most challenging and not very relevant to their everyday life. Moreover, it is pointed out that the affective dimension when teaching physics and chemistry is important. Adopt teaching strategies more "student-friendly" aids enhancing their interest and pleasure in learning (Vilia & Candeias, 2020). The following sections will present the theoretical framework of this study.

Affective Dimension of Learning

The cognitive dimension of learning pertains to knowledge as a mental product and to the learner's independent internal processes that are at their genesis, such as attention, perception, and memory, among others. These processes as a whole are known as cognition. The affective dimension of learning refers to a set of psychological constructs that express a positive or negative connection to the target of affect analysis (Rahayu, 2015). The affective dimension constructs on which this study will mainly focus are interest and attitude. Next, we present a brief description of each.

Interest is a psychological state or an individual predisposition for the learner's engagement with learning, and partially determines what someone decides to learn and how to learn it. According to the literature on interest, its relationship with learning is essentially based on two types of interest, situational and individual. Situational interest is spontaneous and environmentally activated by stimuli at a given moment and context, which may last over time. Individual interest is seen as the learner's lasting predisposition to pay attention to certain stimuli, events, objects, and people, and to engage in a task. Both types of interest lead to a learner's quick reaction in the presence of a learning target, by directing their selective attention towards this target (Ainley, 2006; Hidi & Renninger, 2006). Hidi and Renninger (2006) proposed a four-phase model of interest development: 1) triggered situational interest – a situational interest is stimulated, which is seen as an emotion or an emotional response to the stimulus; 2) maintained situational interest – the interest due to the initial positive emotional state is maintained, if the learner recognizes value in the content to be learned and anticipates that the task demand fits his/her skills, which generates success expectations, positive affect, and engagement; 3) emerging individual interest – in this phase begins to emerge a relatively lasting predisposition of the learner towards the subject; 4) well-developed individual interest – the subject in question is consummated as an individual interest, with the learner actively participating in the task and being capable of resisting frustrations and challenges (Renninger & Su, 2012).

An attitude is a psychological tendency expressed in a favourable or unfavourable assessment of an entity or information about this entity, that one finds or has stored in long-term memory. Attitude is acquired through experience. The response triggered by the attitude object is seen by social psychologists as having three components, namely the cognitive component – the knowledge and beliefs about the attributes of the attitude object; the affective component – emotions or feelings about the attitude object; and the behavioural component – the way one acts towards the attitude object.

Once formed, the attitude object will automatically produce an evaluation bias. However, since attitude is a psychological tendency, it is seen as a non-static inner state of the learner, with greater or lesser temporal stability, and is therefore changeable (Eagly & Chaiken, 1998). In school, attitudes can function as positive or negative factors in learning, with teaching quality being a determining factor in the formation of students' attitudes towards science (Osborne, 2003; Tytler & Osborne, 2012). Thus, optimizing the teaching strategy according to students' characteristics is a good option to stimulate interest and, consequently, improve their attitudes towards scientific subjects.

Constructing Knowledge Based on Students' Experienced Affect in Learning

Ausubel (2000) states that meaningful learning requires learners to be willing to relate the new material to be learned to their structure of knowledge. Thus, the teaching method to be used must also be designed in terms of what students feel about their learning experiences. This influences the students' decision on whether they take an active part in learning. If a task proposed to students is trivial, has a degree of demand for which they lack the required skills, or has a low degree of demand considering their skills, it will likely generate, in that order, apathy, anxiety, or boredom. In those situations, students will probably not engage in their learning. When a high-demand task is matched by a high level of skills, students can potentially engage productively in their learning. The students' feeling of having the potential to successfully solve a proposed challenge will itself motivate their greater engagement in learning as well as feelings of substantive achievement and satisfaction, feeding even more motivation. Although this can lead to a positive experience, it is not a sufficient condition. Students should feel that the task is worthwhile since there is limited satisfaction in being able to do a difficult task well if it seems pointless. If the task is worthwhile to students and fits their learning potential – when the match is optimal –, they will be able to experience what is called "flow" – an internal state of optimal performance, characterized by undivided attention and a high level of engagement in a motivating task intrinsically rewarding. It will be the right task (Goleman, 2020; Taber, 2015). Analogies may be an educational resource that teachers can use for their students to gain flow from learning. On the one hand, analogies enable the development of students' learning in a zone where they have the potential to achieve the intended learning with guidance (Taber, 2015; Taylor & Coll, 2008) – called the "zone of proximal development" by Vygotsky (1978). By using analogies, teachers provide the "need to know" information that can be processed by students in analogical reasoning to achieve the intended learning. Analogies may be a scaffolding tool for tuning the level of demand of a task to match the students' skill level (Harrison, 2008; Taber, 2015). On the other hand, analogies will also allow to adjust teaching to contexts that students consider valuable and useful, helping to capture their interest and to perceive the learning task as worthwhile (Taylor & Coll, 2008).

Analogies in Science Education

Definition of Analogy

Through a careful analysis of the literature, we found variability in the highlighted aspects of what constitutes an analogy. Some authors conceive an analogy as a comparison made between two analogous domains (see Table 1). Nevertheless, there are differences among those who hold this view. While some of these authors do not place any restrictions on correspondences (or mappings) between domains, others do. Gentner (1983) imposes preferential correspondence of relations over what she finds to be attribute similarities (entity properties, such as red and square), as she considers an analogy tends to be made when comparisons exhibit a high degree of relational similarity (Gentner & Markman, 1997). Dagher (2000) mentions that one should compare attributes or relationships between analogous domains. Duit (1991) argues that in an analogy the structures of analogous domains are compared. Other authors, in addition to referring to the comparison made, emphasize the inference of knowledge about the unfamiliar domain through the familiar domain (see Table 1). Others define an analogy as a cognitive mechanism, or identify it as a family of similarities, which include metaphors, models and similes, or even view it as a subset of models (see Table 1).

Table 1

Definitions of analogy from literature

Comparison type between two analogous domains:

i. extension of a simple comparison, in which one seeks to outline multiple points of similarities (Sutton, 1978);
ii. "explicit comparison between one area of knowledge and another area of knowledge that is completely outside the first" (Curtis & Reigeluth, 1984, p.100);
iii. "comparison in which relational predicates, but few or no object attributes, can be mapped from base to target" (Gentner, 1983, p.159);
iv. "process of identifying similarities between different concepts" (Glynn, 1991, p. 223);
v. "correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas" (Glynn et al., 1989, p. 383);
vi. "explicitly compares the structures of two domains" (Duit, 1991, p. 651);
vii. "comparisons of attributes or relationships between the target domain (to be explained) and the analogue or source domain (that is familiar)" (Dagher, 2000, p. 196);
viii. "relation of similarity and/or difference between a model and the world, or between one model and another" (Hess, 2001, p. 299);
ix. "system of relations (correspondences) that hold between parts of the structure of two domains (the analogue or source domain and the target domain)" (Sarantopoulos & Tsaparlis, 2004, p. 35);
x. "connection based on structural similarity between the target and a different case called the base or source" (Clement, J. J., 2008, p. 22);
xi. "comparison between two objects, or systems of objects, that highlights respects in which they are thought to be similar" (Bartha, 2010, p.1)

Comparison type as knowledge inference purpose:

i. "relationship between two entities, processes, or what you will, which allows inferences to be made about one of the things, usually that about which we know least, on the basis of what we know about the other" (Harré, 1972, p. 172);
ii. "explicit comparison between two things in which the similarities, and often the differences, between the things are described. (…) is structured in a way that serves to define some new information in terms already familiar to the learner" (Newby & Stepich, 1987, p. 23);
iii. "explicit comparisons or mappings between similar features of two otherwise different concepts for an explanatory or predictive purpose" (Venville & Treagust, 1997, p. 283);
iv. "not just a comparison between two domains: it is a special kind of comparison that is defined by its purpose and by the type of information it relates. (…) the purpose of an analogy is to transfer a system of relationships from a familiar domain to one that is less familiar" (Orgill & Bodner, 2005, p. 92);
v. "systematic comparisons in which a source situation provides information about a target situation" (Thagard, 2011, p. 132);
vi. "comparisons of structures between two domains based on structural similarities between these domains used to initiate understanding of the key features of a concept to be learned" (Treagust & Duit, 2015, p. 958);

Cognitive mechanism:

i. knowledge acquisition mechanism, with the potential to allow the acquisition of new information through prior knowledge (Vosniadou & Ortony, 1989);
ii. "an inductive mechanism based on structured comparisons of mental representations. It is an important special case of role-based relational reasoning, in which inferences are generated on the basis of patterns of relational roles" (Holyoak, 2012, p. 234).

Family of similarities:

i. "denote a whole family of similarities – including metaphors, models, and similes" (Dagher, 1995, p. 260).

Subset of models:

i. subsets of models, as it involves comparing two things that are similar in some respects (Coll et al., 2005; Coll, 2009; Raviolo & Garritz, 2009).

Considering some of the analogy perspectives presented in the literature as complementary, we define analogy as:

> Relationship, or a system of relationships, of explicit similarities (mappings) between a familiar domain (the analogue) and an unfamiliar domain (the target), inferring knowledge regarding what one knows less from what one knows about the other, through a cognitive process based

on comparison of analogous domains (analogical reasoning) (Vieira & Morais, 2021, p. 730).

The use of analogies has been a common practice in science education. Next, we describe outcomes from the research on the cognitive and affective dimensions of analogies.

The Cognitive Dimension of Analogies

According to research on the effect of using analogies in science teaching, the balance is positive (Aubusson et al., 2006; Duit, 1991). Analogies allow to generate mental models substitutes of abstract concepts, to make unfamiliar or difficult scientific concepts become intelligible (Newby & Stepich, 1987; Venville, 2008; Chinaka, 2021), to promote conceptual changes (Clement, 1993; Eskandar et al., 2013), and to provide a friendlier language to students (Orgill, 2013). However, analogies are not the panacea for science teaching. Analogies has weaknesses. Analogies can never fully describe the concept being taught. This may hinder students' understanding or even lead them to create misconceptions about the target (Orgill, 2013). When teachers use analogies, there is the risk of students developing idiosyncratic interpretations different from the intended way, since they make their own sense of them. Using analogies is a process of personal constructing of meaning, not a simple process of directly transferring knowledge from the analogue to the target concept. It is the student who ultimately must see, understand, and make analogical relations (Haglund & Jeppsson, 2012). It may also be the case that, when presented with a certain analogy, students simply ignore it. The weaknesses in the use of analogies in science education may be mitigated by training the teachers on this subject. Teachers should explain to students what an analogy is and its role; train the use of analogies with students; select analogues familiar to students; diagnose possible misconceptions associated with the analogue and provide a brief explanation about it; as well as use teaching models with analogies (Orgill, 2013). In this study, we used the Focus-Action-Reflection (FAR) guide (Venville, 2008). The three steps of the FAR guide are summarized in Table 2.

Table 2

The FAR guide teaching model with analogies steps

1) Focus: before and in the early part of the lesson.
▪ <u>Before lesson</u>:
- Assessment of whether the target concept is difficult, unfamiliar, or abstract and its difficult aspects for students and to teach.
- Plan de analogy.
▪ <u>Early part of the lesson</u>:
- Find out what students already know about the target concept, its misconceptions, and students' analogue familiarity.
2) Action: during the lesson.
▪ Implement the planned analogy.
▪ Explicitly draw with students the similarities between the analogue and the target concept.
▪ Discussed the features where the analogue is like and unlike the target concept.
3) Reflection: during (following the presentation of the analogy) or after the lesson.
▪ Assessment analogy's effectiveness.
▪ Point out eventual improvements to be made to the analogy in its future use.

Note. (Venville, 2008)

The Affective Dimension of Analogies

Researchers have paid little attention to the affective dimension of analogies (Harrison, 2006; Taylor & Coll, 2008). To the best of our knowledge, Harrison (2002; 2006) was the first to publish research in a school context with the affective dimension of analogies in the foreground. He concluded that analogies can interest students, provided the analogues are contextually, intellectually, and socially familiar. If the analogues are unknown to or poorly visualized by students, then they will feel frustrated or excluded, which will lower their interest in learning. Another conclusion was that the affective dimension of analogies should be a research priority. Based on motivational literature, Harrison (2002; 2006) highlighted that the affective dimension of analogies contributed to the level of student engagement with science and its learning. However, his analysis has a limitation: it was based on the analysis of his past studies with different purposes. Taylor and Coll (2008) wrote a book chapter called "Using analogies to increase student interest in science". These authors emphasize that the affective potential of an analogy is associated with both familiarity and interest in it. An analogy may be familiar but not of students' interest. An analogy should be interesting, in addition to being familiar. This adds an extra dimension of benefits over all others already provided by a familiar analogy. However, these authors did not present empirical evidence.

In most research, the affective dimension of analogies is secondary to the cognitive dimension (Harrison, 2006). Duit (1991) takes the affective dimension of analogies for granted, indicating that "analogies provoke students' interest and may therefore motivate them" (p. 666). Venville and Treagust (1997) only speculated that the interest stimulated in students may be because analogies are typically based on their real-world experience and often provide a better understanding of the concepts taught. Other studies evaluated the impact of analogies on students' interest, motivation and attitudes. Regarding interest, students reported greater interest as a result of teaching methods with analogies (Harrison & Treagust, 2001). Concerning motivation, the conclusions were identical (Curtis & Reigeluth, 1983). As for students' attitudes towards sciences, the impact of using analogies has not always been the same. Sometimes has been positive (Çibik & Yalçin, 2011), other times negative (Gilbert, 1989) or indifferent (Eskandar et al., 2013). Paris and Glynn (2004) found that different types of analogies can impact students' attitudes differently. Sarantopoulos and Tsaparlis (2004) found that using analogies has a positive affective effect on students. However, they admitted a limitation of their research. They could not see whether the effect on affective and cognitive factors was due to the analogy use, to the students' familiarity or interest fostered by the analogy, or to various situations.

Thagard and Shelley (2006) discuss three general classes of analogies related to emotions: i) analogies about emotions – used to describe an individual's emotional state; ii) analogies that generate emotional states; iii) analogies involving the transfer of emotions from an analogue to a target.

It was previously proposed by us to use affective analogies to enhance students' learning and attitudes towards PC. The selection of affective analogies for students depends on their characteristics and those of the teacher. Among the countless possibilities, music was chosen as the analogue domain to teach chemistry. This choice was not fortuitous. Arts (music, dance, drama, fine arts) are seen as a valid alternative approach to the way chemistry is almost always taught. They are a good channel to persuade students that they must study chemistry and to enhance understanding (Vieira & Morais, 2021; Lerman, 2003). The field researcher of this study received formal music training at a Conservatory of Music, in addition to his PhD in Science Education and Communication with a specialization in chemistry teaching. Moreover, it was possible to develop effective analogies between chemistry and music. Vieira and Morais (2021, 2022) showed that teaching chemistry using analogies with music is didactic and fosters chemistry learning among students attending specialized music education schools. Nevertheless, it remains to be empirically clarified whether the gains from the use of musical analogies for teaching chemistry (in the scope of the physics-chemistry subject) are due to familiarity, interest, both factors, or other factors. In this study, the research problem is divided into two main parts: i) to clarify in what way a selected set of analogies between chemistry and music – affective analogies (AA) – constitutes an advantageous didactic resource for students' affect for learning; ii) to clarify whether this analogy strategy benefits the attitudes of these students towards PC. Both parts will be carried out by comparison with a teaching strategy of undifferentiated analogies (UA) and another without analogies (WA), with students who have music as an affective familiar domain. By affective analogies, we intend to mean analogies whose analogue is affective to students in addition to being familiar, and by undifferentiated analogies, analogies whose analogue is familiar to students but does not have affective qualities in addition. Based on the research problem described, we formulated the following research questions:

RQ1: How does the use of analogies between chemistry and music with students who have music as an affective familiar domain, favour students' affect for learning (compared to the use of undifferentiated analogies and the absence of analogies)?

RQ2: Does the use of analogies between chemistry and music with students who have music as an affective familiar domain, benefit their attitudes towards the subject of physics-chemistry (compared to the use of undifferentiated analogies and the absence of analogies)?

RQ3: What is the opinion of students who have music as an affective familiar domain, about the use of analogies between chemistry and music in their learning and in the way they perceive the subject of physics-chemistry (compared to the use of undifferentiated analogies and the absence of analogies)?

By carrying out this study, we looked to help understand the affective and familiar dimensions of analogies' influence on students' affect for learning and attitudes towards science. We sought to fulfil the research needs identified in our literature review of how these analogies qualities favours students' science education through an empirical method.

Methods

Chemistry Concepts and Set of Analogies Developed

To achieve study objectives, three chemistry modules, composed of one or more analogies related to the following themes, were developed: 1) Kinetic-molecular theory; 2) Quantum model of the atom; 3) Chemical elements and their isotopes. Moreover, analogies between chemistry and music were developed for these modules. To teach kinetic-molecular theory and the quantum model of the atom, we developed the following analogies: the "Marching band analogy" (Vieira & Morais, 2021) and the "Happy birthday song analogy", the "Musical notes analogy", and the "Concert band playing in a bandstand in the middle of a park analogy", respectively (Vieira & Morais, 2022). To teach the concept of chemical elements and isotopes, another analogy was created using a family of musical instruments, the saxophones. We also developed undifferentiated analogies homologous to the chosen affective analogies. Table 3 presents the target topics of each module and the corresponding description of the affective and undifferentiated analogies, as well as the teaching strategy without analogies.

Setting and Participants

This study used an explanatory mixed-method design. The quantitative approach was used to find a cause-effect relationship between the teaching strategy and the students' attitudes towards PC. We conducted a pre-test–post-test comparison group quasi-experimental design since it was not possible to randomly assign individual participants to experimental and control groups. Groups were already formed. Given the interest in comparing the effect of three teaching strategies we created three groups: the affective analogies (G_{AA}) – the experimental group – the undifferentiated analogies (G_{UA}) and the group without analogies (G_{WA}) – both control groups. The treatment administered to each group was the corresponding teaching strategy for the three modules described in Table 3. To reduce some threats to study's internal validity, students' positive affect for music was pre-checked and the teacher was the same for all interventions. The qualitative approach was used to understand and explain quantitative results and to clarify how the selected musical analogies fostered the students' affect for learning, with the aid of semi-structured interviews.

Table 3

Description of the three teaching strategies versions of the three chemistry modules

Module	Target topic	Teaching strategy	Description
Kinetic-molecular theory	The particulate nature of matter	AA	Marching band performance in a football stadium, when observed from a helicopter without and with a magnifying camera vs. Matter at a macroscopic and microscopic levels
		UA	Football team training in a stadium, when observed from a helicopter without and with a magnifying camera vs. Matter at a macroscopic and microscopic levels
		WA	Theoretical explanation of characteristics of matter at a macroscopic and microscopic levels
	The microscopic properties of matter	AA	Musicians' behaviour of a marching band performance in a football stadium within three typical scenarios vs. The energy, the dynamics, and the relative space of the particles of a material in three states of matter – solid, liquid and gas
		UA	Football players' behaviour training in a football stadium within three typical scenarios vs. The energy, the dynamics, and the relative space of the particles of a material in three states of matter – solid, liquid and gas
		WA	Theoretical explanation of the properties of solid, liquid and gaseous materials at the microscopic level
			Family of musical instruments (example used: saxophones) vs. Chemical elements
	The relationship between temperature, energy, and the particles of matter, with no physical state change	AA	Tempo effect on the performance of a marching band in a football stadium vs. The temperature effect on particles of a material
		UA	Training intensity effect on the performance of football team training at the stadium vs. The temperature effect on particles of a material
		WA	Theoretical explanation of the relation between temperature, energy, and the particles of matter
Quantum model of the atom	The atom concept	AA	Bars of the "Happy Birthday" song vs. Atoms of a material
		UA	House divisions vs. Atoms of a material
		WA	Theoretical explanation of atoms as one of the structural units of matter
	Subatomic particles and their electric charges	AA	Musical notes (sharp, flat, natural) vs. Subatomic particles (protons, electrons, neutrons)
		UA	Object colours (dark, light, transparent) vs. Subatomic particles (protons, electrons, neutrons)
		WA	Theoretical identification of the subatomic particles and their electric charges
	The atomic structure	AA	Concert band playing at a bandstand in the middle of a park with listeners around vs. Atomic structure according to the quantum model of the atom
		UA	Bee colony around a hive at the middle of a park vs. Atomic structure according to the quantum model of the atom
		WA	Theoretical explanation of the atomic structure according to the quantum model of the atom
Chemical elements and their isotopes	Chemical elements	AA	Family of musical instruments (example used: saxophones) vs. Chemical elements
			Variation of the musical instrument family (example used: each of the saxophones belonging to the saxophone family) vs. Isotopes
		UA	Family of true twins vs. Chemical elements
		WA	Theoretical explanation of the chemical element concept
	Isotopes	AA	Variation of the musical instrument family (example used: each of the saxophones belonging to the saxophone family) vs. Isotopes
		UA	True twins vs. Isotopes
		WA	Theoretical explanation of the isotopes concept

Note. AA = affective analogies; UA = undifferentiated analogies; WA = without analogies

Participants in this study were 147 students (75 girls, 51.0 %, and 72 boys, 49.0 %), between 11–13 years of age (*M* = 12.0, *SD* = 0.35), enrolled in the seventh grade of a middle school music course during the year 2018/19, in one of four specialized music education schools from the northern region of Portugal, selected by a convenience sampling. Besides the musical subjects provided to students who aim to pursue a music career, the course curriculum includes general education subjects, such as PC. At the schools, it was impossible to randomly assign individual participants to treatments. However, the treatments were randomly assigned to the groups already formed. The number of students per group in the total sample, as well as their gender and age, were identical (Table 4).

Table 4

Characterization of groups in the total sample

Group	Number of students			Age (years)	
	Girls	Boys	Total	M	SD
Affective analogies	27 (54.0 %)	23 (46.0 %)	50	12.0	0.43
Undifferentiated analogies	24 (48.0 %)	26 (52.0 %)	50	12.0	0.33
Without analogies	24 (51.1 %)	23 (48.9 %)	47	11.9	0.25

By the time of the study, the participants were attending PC for 2–3 months and studying chemistry for the first time. They also had been playing a musical instrument for 1–9 years (*M* = 5.55 years, *SD* = 1.92).

Instruments for Data Collection

Aiming to control students' affect for music and to measure students' attitudes towards PC, two questionnaires were selected from the literature: the Music USE (MUSE) questionnaire (Chin & Rickard, 2012) and the Attitudes towards Physics-Chemistry (AtPC) questionnaire (Vilia & Candeias, 2020; Neto et al., 2013), respectively. The construct validity and the internal consistency reliability of both questionnaire scales were studied through exploratory factor analysis (EFA) and Cronbach's alpha approach with 608 students, similar to the sample of this study. Moreover, face validity was verified with 10 of these students. First, students were asked to complete questionnaires. Afterwards, they were questioned verbally regarding their overall understanding of the questionnaires and each of their items. It was found that this was understood as expected by all participants. Content validity was not analysed since it was assured by their authors. The MUSE questionnaire is an instrument originally developed to measure engagement in music. The students' affect for music was deduced using this questionnaire, since underlying the degree of engagement with an activity is the affect one has on it (Chin & Rickard, 2012). The language of the existing questionnaire was English, and the participants of this study were Portuguese. After obtaining permission from the authors, the MUSE questionnaire was translated into Portuguese and culturally adapted. It is composed of two sections. The first allows us to quantify the respondents' indices of Music Training (IMT), Music Instrument Playing (IMIP), and Music Listening (IML), through a set of questions. The second section included 24 items, on a 6-point Likert-type Music Engagement Style (MES) scale, ranging from not applicable to me (0) to strongly agree (5). An EFA using principal components with varimax rotation was conducted. The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for the analysis, KMO = 0.859, and a significant Bartlett's test of sphericity $\chi2$ (171) = 3667.942, $p < .001$, indicated that correlations between items were sufficiently large for factor analysis (Field, 2009). Based on the Kaiser's and scree plot criteria (Field, 2009) five factors were retained: 1) "Engagement production" – music production for mastery of playing or improvisation skills; 2) "Cognitive and emotional regulation"; 3) "Social connection"; 4) "Physical exercise"; 5) "Dance". The first factor comprises 7 items (10, 14, 15, 18, 26, 28, 29); factor loads were between 0.586 and 0.758. The second factor comprises 4 items (17, 21, 25, 30); factor loads were between 0.675 and 0.709. The third factor comprises 3 items (11, 19, 23); factor loads were between 0.804 and 0.827. The fourth factor comprises 3 items (12, 24, 32); factor loads were between 0.610 and 0.809. The fifth factor comprises 2 items (20, 27); factor loads were between 0.860 and 0.882. All the identified items demonstrated a high factor loading on the target factor (Fenn et al., 2020). The remaining items were excluded since they loaded more than one factor or did not have the desired factor loading (≥ 0.500). The five factors extracted explained 62.494 % of the total variance, indicating low discrepancy between structure and data (Fenn et al., 2020). Moreover, they correspond to the five subscales proposed by the authors' scale. The Cronbach's alpha value for the MES scale was 0.86, and for subscales 1 to 5 the values were 0.81, 0.71, 0.84, 0.74, and 0.85, respectively. These values indicate adequate internal consistency (Tsang et al., 2017). The AtPC questionnaire was developed to measure students' attitudes towards the discipline of physics-chemistry on school achievement. It includes 26 items on a 4-point Likert-type scale, ranging from strongly disagree to strongly agree. An EFA using principal components was conducted. The KMO value of 0.944 verified the sampling adequacy for the analysis, and a significant Bartlett's test of sphericity $\chi 2$ (210) = 5949.778, $p < .001$, indicated that correlations between items were sufficiently large for factor analysis (Field, 2009). Based on the Kaiser's and scree plot criteria (Field, 2009) four subscales were retained: 1) "Affect for PC"; 2) "Cognition and values" – the usefulness of PC; 3) "Behaviours and achievement" – behaviours and performance related to PC; 4) "Affect for the study of PC". The first factor comprises 7 items (2, 3, 6, 13, 18, 19, 31); factor loads were between 0.649 and 0.881. The second factor comprises 5 items (10, 20, 22, 23, 24); factor loads were between 0.652 and 0.757. The third factor comprises 5 items (1, 4, 5, 7, 26); factor loads were between 0.593 and 0.787. The fourth factor comprises 4 items (8, 14, 17, 25); factor loads were between 0.611 and 0.787. All the identified items demonstrated a high factor loading on the target factor (Fenn et al., 2020). The remaining items were excluded for the same reasons presented in the case of the MUSE questionnaire. The four factors extracted explained 66.212 % of the total variance, indicating low discrepancy between structure and data (Fenn et al., 2020). The Cronbach's alpha value for the AtPC scale was 0.93, and for subscales 1 to 4 the values were 0.87, 0.82, 0.92, and 0.83, respectively. These values indicate adequate internal consistency (Tsang et al., 2017). As a result, the MES and AtPC scales are found to provide valid and reliable data for assessing, respectively, the music engagement style and the attitudes towards PC of our research participants.

We also conducted semi-structured interviews of 15-20 minutes, following the end of quantitative data collection. After the treatment was administered and students become familiar with all teaching strategies used, they were asked to assess them comparatively in the cognitive and affective perspectives of learning. Furthermore, students were also asked to analyse the relationship between the use of musical analogies and their opinion about PC in comparison to the use of undifferentiated analogies and the absence of analogies. By seeking to distinguish between the students' cognitive and affective arguments, the aim was to help better understand the various phenomena under study. The set of predetermined questions for the semi-structured interviews is presented in Table 5.

Procedure

The research was put into practice in all groups G_{AA}, G_{UA}, and G_{WA} of the four participating schools through six 50-min interventions over 4 months. In the first intervention, the chemistry concept was introduced and the AtPC (pre-test) and the MUSE questionnaires were applied. In the following three interventions, the treatment was administered through multimedia presentations of each of the three modules.

Table 5

Questions for the semi-structured interviews

Questions
1. Indicate, giving reasons, which teaching strategy provided a better learning of chemical concepts taught.
2. Of all the teaching strategies used to teach chemistry, which one did you most enjoy and why?
3. Explain the effect of a frequent use of musical analogies in your chemistry learning would have on your opinion regarding the subject of physics-chemistry.

In the fifth intervention, the AtPC questionnaire was applied again (post-test), all the teaching strategies under study were made known through a multimedia presentation, and a sample of around 25 % of students from each group were interviewed at the same time. The referred multimedia presentation consisted of one target topic of each chemistry modules, taught through the three teaching strategies in comparison. The group interviews were the achievable solution found to get specific views from several participants through interviews in the reaming 15-20 minutes of the fifth intervention. The research intervention had to comply with the school schedule (50-min lessons). To ensure that all participants had their say, using a semi-structured interview schedule (Table 5), it was posed each question, elicited a response, and passed it off to another participant until all group had the opportunity to answer. The criterion used for the sample size of the group interviews was the time available. The sample selection approach used was a random purposive sampling (Gay et al., 2012). Of the 147 study participants 60 were interviewed (G_{AA}: 21, G_{UA}: 20, G_{WA}: 19). In the sixth intervention, the features where the analogues are like/unlike the target concepts were discussed, aiming to confirm analogies' effectiveness and to handle with weakness of the analogies can never fully describe the concept being taught. The teaching with analogies model underlying this procedure was the FAR guide.

Permission from school directors and informed parental consent were obtained. Students' participation was voluntary, and the anonymity and confidentiality of all data were ensured.

Data Analysis

The quantitative data collected were analysed with IBM SPSS Statistics 27. Regarding the data of the MUSE questionnaire, the indices and styles of music engagement were determined according to the questionnaire's scoring sheet (Chin & Rickard, 2012) and the EFA, respectively. Students' affect for music was inferred based on the mean values of the IMT and IMIP indices and music engagement style. The IML index was not used, because a high amount of music intentionally heard does not imply a positive affect for music. To verify the equivalence of the groups regarding students' affect for music, a one-way ANOVA (analysis of variance) was performed to test whether all groups' IMT and IMIP indices and music engagement styles means were equal. With the data collected using the AtPC questionnaire before (pre-test) and after treatment (post-test), a two-way mixed (repeated measures plus a between-group variable) ANOVA was conducted to determine whether the teaching strategy (AA, UA, and WA) had a differential effect on students´ attitudes towards PC over these two-time points (Field, 2009). The three different treatments reflect the three groups of the between-group variable – G_{AA}, G_{UA}, and G_{WA}. Since ANOVA is an omnibus test statistic (Field, 2009), in the case of a statistically significant interaction effect between time and the teaching strategy, a two-way mixed ANOVA was applied again to each pair of groups to locate the source of the statistically significant differences. Considering the behaviour of students' attitudes subscales could be different, an inferential analysis identical to that performed on the total scale was also conducted on the subscales. It is worth noting that the significance level used to retain or reject the null hypothesis of the statistical tests was $\alpha = 0.05$. All the assumptions of the statistical tests used were previously checked. Moreover, we only analysed the interaction effect of the two-way ANOVAs, since what is at stake is the differential efficacy of different teaching strategies between pre-test/post-test.

The analysis of qualitative data was performed using the thematic categorical analysis technique (Bardin, 2009). Two themes were defined: 1) "Students' assessment of teaching strategies used"; 2) "Students' opinion towards PC and its relationship with the use of musical analogies". The analysis categories established for both themes were "Cognitive perspective" and "Affective perspective". The analysis subcategories for theme 1 were the teaching strategies under analysis and their combinations. For theme 2, the analysis subcategories were "Attention", "Memory", "Content relevance" and "Comprehension", and "Interest", "Emotions" and "Motivation", for the "Cognitive perspective" and the "Affective perspective" categories, respectively.

Results

In this section, we begin by presenting the analysis of students' affect for music, as well as the effect of the teaching strategies. Subsequently, we analysed the results of students' interviews.

The mean values for the indices and styles of music engagement collected using the MUSE and presented in Table 6, show that students had positive affect for music. The IMT (*M* = 7.22, *SD* = 1.19) and IMIP (*M* = 7.00, *SD* = 3.39) indices were high for their age. The IMT max value is 8. The IMIP mean was considered high, as students had been playing a musical instrument, on average, for 5.55 years (*SD* = 1.92), 1.41 hours a day (*SD* = 0.90), less than a week ago. Moreover, besides the high mean of "Engagement production" (*M* = 4.18, *SD* = 0.48), it was the highest mean score obtained for the students' music engagement style. By analysing Table 6, it is possible to observe the equivalence of the groups regarding students' affect for music. The significance values of the *F*-test show that mean differences for indices and styles of music engagement were not significant between groups.

Table 6

Means, standard deviations, and one-way ANOVA for the indices and styles of music engagement

Variable		G_{AA}		G_{UA}		G_{WA}		Total		ANOVA		
		M	SD	M	SD	M	SD	M	SD	F (2, 137)	*p*	η^2_p
Indices of music engagement	IMT (Max = 8)	7.13	1.21	7.38	1.08	7.16	1.29	7.22	1.19	0.60	.550	.009
	IMIP	7.25	3.37	6.98	3.84	6.75	2.91	7.00	3.39	0.23	.793	.004
Styles of music engagement	Engagement production	4.27	0.40	4.17	0.56	4.08	0.45	4.18	0.48	1.78	.172	0.25
	Cognitive and emotional regulation	4.29	0.63	4.02	1.20	3.88	0.88	4.07	0.94	2.34	.100	.033
	Social connection	3.36	1.38	3.16	1.21	3.32	1.13	3.28	1.24	0.36	.696	.005
	Physical exercise	3.82	0.91	3.83	1.17	3.70	0.90	3.79	1.00	0.24	.790	.003
	Dance	2.86	1.70	3.15	1.70	2.40	1.91	2.81	1.78	2.09	.127	.030

Note. IMT = Index of Music Training; IMIP = Index of Music Instrument Playing; G_{WA} = affective analogies group; G_{WA} = undifferentiated analogies group; G_{WA} = group without analogies; ANOVA = analysis of variance.

The teaching strategies AA, UA and WA had a differential impact on students' AtPC (Table 7). There was a significant interaction effect between time and the teaching strategy used (F (2, 128) = 5.68, p = .004, η^2_p = .082). According to two-by-two group comparisons between pre-test/post-test, statistically significant differences occurred between G_{AA} and G_{WA} (F (1, 83) = 8.65, p = .004, η^2_p = .094), and G_{UA} and G_{WA} (F (1, 86) = 8.37, p = .005, η^2_p = .089). If only these results and the evolution of students' AtPC between pre-test/post-test, presented in Table 7, had been considered, the analysis would be: the use of analogies, affective or not, improves students' attitudes; the affective dimension of analogies has no differential effect on students' attitudes; teaching without analogies causes a retrogradation of students' attitudes. However, considering the AtPC scale consists of four latent subconstructs (i.e., "Affect for PC", "Cognition and values", "Behaviours and achievement", "Affect for the study of PC"), all of which contribute to students' AtPC, the balance is different and more detailed. The use or not of analogies had no differential effect on the students' "Affect for PC" and "Cognition and values". There was only a significant interaction effect between time and students' "Behaviours and achievement" (F (2, 128) = 6.77, p = .002, η^2_p = .096), as well as "Affect for the study of PC" (F (2, 128) = 6.13, p = .003, η^2_p = .087) (Table 7). To break down these interactions, two-by-two group comparisons between pre-test/post-test were performed. Regarding students' "Behaviours and achievement", these comparisons revealed statistically significant differences between G_{AA} and G_{WA} (F (1, 83) = 10.19, p = .002, η^2_p = .109) and G_{UA} and G_{WA} (F (1, 86) = 11.94, p = .001, η^2_p = .112). This indicates that both teaching with AA and UA made it easier for students to learn and achieve better, whereas WA had the opposite effect. Regarding students' "Affect for the study of PC", the comparisons performed revealed statistically significant differences between G_{AA} and G_{WA} (F (1, 83) = 10.84, p = .001, η^2_p = .115) and G_{AA} and G_{UA} (F (1, 87) = 4.68, p = .033, η^2_p = .051). This indicates that teaching with AA improves students' affect for the study of PC, and UA or WA worsens it.

Table 7

Means, standard deviations, and two-way ANOVA for attitudes towards physics-chemistry and its subscales

AtPC	G_{AA}		G_{UA}		G_{WA}		ANOVA				
	M	SD	M	SD	M	SD	Effect	F ratio	df	p	η^2_p
Total scale:											
Pre-test	2.73	0.53	2.96	0.43	2.92	0.43	T	1.15	1, 128	.286	.009
Post-test	2.80	0.48	3.01	0.40	2.66	0.43	TS	4.54	2, 128	.013	.066
							TS*T	5.68	2, 128	.004	.082
Subscales:											
Affect for PC											
Pre-test	3.02	0.63	3.28	0.64	3.20	0.54	T	3.30	1, 128	.072	.025
Post-test	2.92	0.72	3.33	0.55	2.89	0.63	TS	5.59	2, 128	.005	.080
							TS*T	2.69	2, 128	.072	.040
Cognition and values											
Pre-test	2.96	0.59	2.96	0.62	2.96	0.54	T	0.06	1, 128	.802	< .001
Post-test	2.97	0.55	3.04	0.58	2.82	0.50	TS	0.68	2, 128	.509	.010
							TS*T	1.18	2, 128	.311	.018
Behaviours and achievement											
Pre-test	2.71	0.60	2.91	0.55	2.99	0.52	T	0.20	1, 128	.658	.002
Post-test	2.87	0.51	3.04	0.52	2.78	0.52	TS	2.04	2, 128	.134	.031
							TS*T	6.77	2, 128	.002	.096
Affect for the study of PC											
Pre-test	2.28	0.67	2.70	0.60	2.52	0.73	T	2.04	1, 128	.156	.016
Post-test	2.47	0.61	2.59	0.54	2.16	0.70	TS	4.43	2, 128	.014	.065
							TS*T	6.13	2, 128	.003	.016

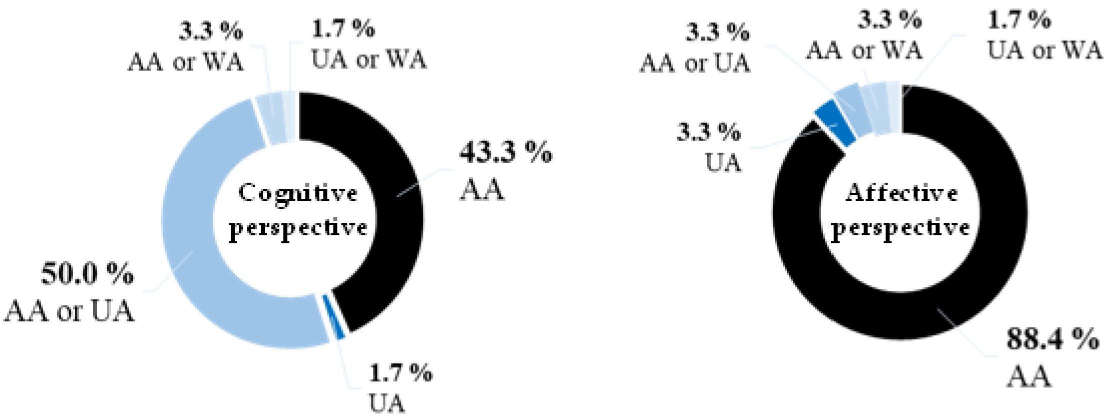
Note. AtPC = attitudes towards physics-chemistry; G_{WA} = affective analogies group; G_{WA} = undifferentiated analogies group; G_{WA} = group without analogies; T = time; TS = teaching strategy; ANOVA = analysis of variance.

This part will now focus on the analysis of the interviews. This enabled us to understand students' preferred teaching strategies to learn chemistry, according to the cognitive and affective perspectives, as well as the reasons underlying their selections (theme 1). From a cognitive perspective, students' answers were essentially divided into two subcategories (Figure 1). Half of the interviewees placed the AA and UA at the same level regarding the understanding achieved. They provide a better concept understanding in terms of what is familiar, something that the teaching strategy WA does not allow: "Analogies with music or the others are the same. Comparison helps.

Without analogies it is more difficult to understand because we do not have something to associate with". Furthermore, they also contribute to better knowledge retention: "It facilitates memorization. We have more memorization options". On the other hand, 43.3 % of the interviewees preferred AA. They believed the musical analogies provided a superior quality of knowledge acquisition and retention: "With music, I understood better, and it is catchy". This comes from their affect for music, which gives rise to greater content relevance, interest, and attention: "It was easier with music. It is something we are used to. We like music! It awakens more interest. We pay more attention and learn better. When thinking about the musical analogies, it becomes easier to remember chemistry". From an affective perspective, students' teaching strategy preferences were unequivocal. The subcategory AA was indicated by 88.4 % of the interviewees. All the interviewees who had already preferred AA in the cognitive perspective also preferred AA in the affective perspective (49.1 %). They justified their predilection again with the higher quality of learning provided. Indeed, their affect for music gave rise to a greater affect for learning chemistry: "Music is more motivating. We understand better… when we understand something, we like it… if there is an area that we like, it captivates us to study the other area". The remaining 50.9 % of interviewees, who preferred AA from an affective perspective, corresponds to almost everyone who preferred AA or UA from the cognitive perspective (27 of 30). They explain that their affect for music was the reason for their option: "I think the comparison is the same [AA and UA]. Since we like music, the analogies with music are more interesting. I will enjoy studying more and being happy". These students even stated that, as it fits their profile, the use of analogies between chemistry and music should be something to put into practice in their classes: "(…) because we are at a music school, I think everything is exactly right… the school could do it".

Figure 1

Students' teaching strategy preference to learn chemistry from the cognitive and affective perspectives



Note. AA = affective analogies; UA = undifferentiated analogies; WA = without analogies.

The analysis of the interviews also helped us to understand students' opinions towards PC and its relationship with the use of musical analogies (theme 2). The vast majority (82.5 %) of students interviewed about this theme (n = 40) believed these analogies benefit their opinion towards PC. The following statements are examples of this: "I already like the subject, with music I like it even more; I do not really like PC. With music it would be much better". The main arguments presented were related to affective aspects, namely the arousal of positive emotional states and more intense interest in learning. In this context, some interviewees also reported cognitive aspects mentioned before, such as greater attention, understanding, knowledge retention, and, mostly, the relevance of the content taught. All these arguments come from their affect for music. All the passages transcribed for the AA subcategories of theme 1 are representative of the arguments used for all theme 2 categories and subcategories. Only 12.5 % of the interviewees believed the use of musical analogies to be indifferent to their opinion towards PC, and 5 % had an adverse effect. They were satisfied with how their teacher taught and said that teaching chemistry always with music could be boring, respectively.

Discussion

Aiming to understand how the use of analogies between chemistry and music – AA – favours the affect for learning among students who have music as an affective familiar domain, and whether these analogies benefit students' AtPC, we conducted a comparative evaluation with the use of UA and a teaching strategy WA. Among the strategies evaluated, AA was the students' predilection. The affective dimension of the analogies added to the familiar dimension increased students' active engagement in learning and desire to learn. This result adds empirical support to Taylor's and Coll's (2008) ideas. Before, Sarantopoulos and Tsaparlis (2004) demonstrated that the use of familiar and interesting analogies had a positive affective effect. However, they were unable to determine whether the observed gains were due to the analogies used, to the familiarity or interest factors, or their combination. Our results suggest familiarity and interest factors. Moreover, indicate a preponderance of the interest effect over familiarity. The students who preferred AA in the affective perspective of learning always supported their option in comparison to UA. The interest stimulated was higher due to their affect for music. This shows that familiarity fosters affect for learning, but to a lesser degree than interest. Furthermore, half of these students stated the interest factor was crucial for their choice. From a cognitive perspective, AA or UA were equal for them. The familiar dimension of the analogies enables teachers to teach students in their zone of proximal development, providing guidance that brings learning to a demanding level, for which they feel that have a high chance of being successful. The sense of understanding triggers motivation, engagement, a sense of achievement, and satisfaction, thus fostering affect for learning. Nevertheless, there is limited satisfaction in being able to do a high-demand task well, if it does not seem worthwhile to students (Taber, 2015). The affective gains from using analogies due to their familiarity are therefore small compared to the interest. They will only be substantial if the analogies are also of interest to students. The affective analogies have the potential to provide students with a fulfilling learning experience. In general, the way this is processed is related to the ability of analogies to transfer affect from the analogue to the target (Thagard & Shelley, 2006), in this case, from music to chemistry. The students made it clear. Including music in their chemistry learning has fostered or increased students' affect for learning and PC. The four-phase model of interest development, proposed by Hidi and Renninger (2006), provides a rationale for the mechanism we believed to have mediated this transfer: 1) a situational interest in learning the chemical concepts was triggered by the musical analogies used, arousing positive emotions and focused attention, due to students' individual interest in music; 2) the meaningfulness of the task and students' engagement provided by the familiarity and interest of these analogies, as explained before, supported and sustained the situational interest over time; 3) from module to module, based on previous engagement, as well as stored knowledge and stored value, an individual interest in learning chemistry was emerging or reinforced, depending on students – the reengagement of students across modules is evidence of this; 4) a well-developed individual interest for learning chemistry and for PC was accomplished or enhanced, fostering intrinsic motivation in students for the subject – they showed predisposition to reengage with chemistry and PC in the future. Although the musical analogies benefited students' affect for learning, students were divided regarding their preferred teaching strategy from a cognitive perspective. Half of the interviewees believed the effect on their level of learning of both teaching strategies with analogies was equally higher than WA, and 43.3 % believed the AA effect was higher than UA and WA. Considering psychologists' (Goleman, 2020) and neuroscientists' ideas (Damásio, 2006; Jensen & McConchie, 2020) that positive affect favours students' cognition and consequently their learning, there was an expectation that the teaching strategy AA would be preferred. It is presumed that the assistance provided by the familiar dimension of analogies was, per se, enough for students to engage in learning and understand the concepts taught, leaving no margin for learning level gains from the alleged benefits of the affective dimension of analogies. Given students' ambivalent opinions, it is supposed that the positive affective dimension of analogies may not be as decisive for their learning level. On the contrary, if it is familiar to them, the most decisive thing may be that the analogy does not repulse students to the point of alienating them from their learning. From this perspective, for the benefit of students' learning, more than an analogy being familiar and interesting, it should perhaps be familiar and not aversive.

The results of this study indicate that using AA benefits students' AtPC compared to the other teaching strategies evaluated, especially in comparison to WA. This is shown by the balance of the AtPC subscales analysis and corroborated by the data collected in the interviews. Of the interviewed students, 82.5 % reported this. It fostered positive emotions and interest in learning, due to their affect for music. The benefit of students' AtPC with the use of AA was as expected since these analogies were tailored to students' knowledge and interests. However, opposite to what was predicted, there was no differential effect between AA and UA regarding the "Behaviours and achievement" subscale. This is evidence that gives credence to the hypothesis raised above that the positive affective dimension of analogies may not be as important for students' learning levels. Regarding the "Affect for studying PC" subscale, we expected the mean of G_{AA} to evolve between the pre-test/post-test from a negative to a positive level (≥ 2.50), since students stated that AA promoted a higher interest for learning. It was close (2.47). This would have probably been achieved with a few more interventions.

Conclusion

In this study, we proposed to find out whether the teaching of chemistry through a set of analogies between chemistry and music – affective analogies – to 7th-grade students of specialized music education schools would be beneficial for the development of students' affect for learning and positive attitudes towards PC, compared to teaching with undifferentiated analogies and without analogies. Its results allow us to conclude that, in the affective perspective of learning, an analogy should be familiar and affective. Both dimensions promote positive affect for learning. Moreover, we found that the affective dimension of analogies is more crucial than the familiar dimension for students' affect for learning. The affective dimension of analogies fosters positive affect for learning at a much higher level. Considering that it better fits their profile, with emphasis on their positive affect for music, students indicated the teaching strategy with affective analogies as the most relevant for their learning. It was the strategy that led to greater attention, interest, and understanding, and, therefore, a greater positive affect for learning. The students' affect for music was transferred to their learning and to the physics-chemistry subject. From the cognitive perspective of learning, it seems that the positive affective dimension of analogies does not have such a preponderant effect on students' learning, as long as the analogy is familiar to them. More than familiar and affective, an analogy should be familiar and non-aversive. As for the attitudes towards physics-chemistry subject, we concluded that students benefit from teaching with affective analogies, especially when compared to teaching without analogies. This comes from the students' perception that this teaching favoured their affect for the study of physics-chemistry in comparison to undifferentiated analogies and the absence of analogies, due to their positive affect for music. Furthermore, it favoured their learning and achievement in physics-chemistry, in comparison to the absence of analogies, since it was easier for students to learn and to achieve better with analogies.

The results and conclusions revealed by this study helps to the development of the state of the art on the use of analogies in science education. The research legacy is huge, particularly regarding its cognitive dimension. There are many investigations concerning the effectiveness of analogies in instruction and textbooks (strengths and weaknesses), teaching with analogies models, teacher's use of analogies in their classes, the effects of different types of analogy on students' learning, the development of effective analogies to teaching abstract, unfamiliar or difficult scientific concepts, and preservice and inservice teachers' education on analogies use. This research focused on the effect of the affective dimension of analogies on students', which is an issue less investigated and reported. It has been stated in literature that the affective dimension of analogies impacts favourably students' affect towards science and its learning due to familiar and interest qualities of an analogy. Nevertheless, this claim lacked empirical support. It was essentially made based on motivational and self-efficacy theories. Moreover, doubts were raised regarding the influence level of each of these qualities of the analogies on affective and cognitive factors of students learning and how it proceeds. This study contributes to empirically clarifying how the affective and familiar dimensions of an analogy foster students' affect for learning and positive attitudes towards science and help them achieve a successful education. We also proposed a mechanism through which this can occur. Further research with even more students during more time in other situations, using the same and other sets of analogies restricted by the operational definitions made on the dependent variables in this study, will help to attest and generalize widely our findings. Moreover, the application of achievement tests will give us more information.

Educational Implications

Based on our literature review and results, there are some educational implications that we should consider. The education of students tends to be more successful if it is tailored to their specificities. Not only should students be guided vocationally towards a curricular area for which they are expected to have a greater predisposition, but it also helps to adapt the curriculum to their profile. Everyone deserves the right to access a set of fundamental knowledge and use it competently, towards becoming a future citizen and adapting to society. One way to meet that aim involves teaching that emphasizes areas/subjects for which students are more predisposed, at the service of the evolution of skills for which they have less aptitude and/or affect. In this sense, not only should we diagnose students' prior knowledge, but also their profile. This will help to identify opportunities for meaningful learning and to improve their weaker skills in line with the stronger ones. Another way is to teach considering the cognitive and conceptual readiness of the students, aiming not only at their understanding of what is established by the curriculum, but also at making them feel that what they learn makes sense. The positive experience of each learning task supports the feeling that they are in control, sowing seeds to expand the limits of their abilities through positive feedback cycles that keep them involved and with the confidence to expend additional effort, if necessary, constituting the achievement of excellence in learning their personal fulfilment. The relevance of the intellect, through teaching that focuses on students' perceptions of making sense (affect), could be more important than the relevance of problems or everyday contexts used (familiarity). Teachers must seek to know how students feel during their learning experiences and make use of their emotional intelligence to build positive engagement learning cycles and prevent them from breaking.

As for the use of analogies in the teaching of scientific concepts, the most significant thing that can be taken from this study is mainly related to its qualities. An analogy should be familiar and interesting. Nevertheless, to take advantage of the potential of analogies use to teach science efficiently, it is also important not to forget the precautions mentioned in our literature review.

Limitations

Due to organizational and practical constraints, it was not possible to randomly select each of the participants from the identified population for each of the necessary research groups, thus not having total guarantees of the representativeness of the sample. In each of the participating schools, students were only available in groups or classes already formed, on predefined days and hours, which jeopardized the meaning of the results (internal validity), as well as their application to other samples and situations, and their generalization to the defined population (external validity).

Regarding data collection, despite the fact the research focused on chemistry target topics in formal learning contexts, it was used an instrument to measure attitudes towards physics-chemistry subject. In the middle school national curriculum, chemistry is taught in this subject. It was not possible to interview students individually. Although we encouraged students to provide independent thoughts and sincerity, the opinions of some students may have been conditioned by those of their peers in the group interviews. All the assessments made to analyse the effect of musical analogies used for teaching chemistry were self-reported by the students. Nevertheless, care was taken to use effective musical analogies to teach the target topics. Almost all of them were assessed in research made before (Vieira & Morais, 2021, 2022). Of eight homologous analogies of the musical ones used, three (37.5 %) came from a football training context. These were those found at the time of the study. This may introduce some interference on the dependent variables in replications of this study, if participants enjoy football.

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