



Establishing the norms of the Vygotskian teaching in the science classroom

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Abstract. This study aimed to exemplify an approach to in-class science inquiry teaching for effective science knowledge acquisition of students. The teaching tool (argument-based inquiry) is presented within a specific instructional psychology context, coined as discursive psychology, grounded on the seminal works of Lev S. Vygotsky. According to Vygotsky, concept formation or learning science concepts requires the acquisition of a version of specific social languages or thinking and talking systems by which science ideas are generated and labelled. In the classroom, there are at least two social languages that may have differences and communalities. On one hand, students may bring a less formalised everyday social language into the classroom. On the other hand, science teachers have to share an alternative social language favouring and featuring a more formalised thinking and talking system attaching to canonical science knowledge. This study thus presented an expanded illustration how the science teacher uses an in-class science inquiry approach by reacting to the existences of the different or exclusively mutual social languages or pedagogical accountabilities.

Keywords: Vygotskian perspective, science learning, classroom discourse, social languages, learning demand, social negotiations of meanings

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Introduction

The purpose of the current study is to describe learning and teaching phenomenon from the Vygotskian perspective and to provide a pedagogical thinking toolkit regarding how a teaching sequence can be planned, composed and implemented. At the outset, Vygotskian concepts of (science) teaching and learning are introduced. Then, research-based examples are presented to improve an understanding how Vygotskian perspective is instrumental and serviceable in preparing and implementing in-class science inquiry activities.

Theoretical Underpinnings

This study is framed by the core ideas of the Vygotskian and neo-Vygotskian perspective that were re-designed and appropriated for instructional purposes (Daniels, 2001; Mercer, 2010; Wertsch, 1985). In this section, ideas characterising the assumptions of this study are briefly introduced in justifying the place of social language phenomenon for teaching and learning science concepts.

Vygotsky's General Genetic Law of Cultural Development

Vygotsky (1978) proposed ontogenetic development idea. This refers that there is a distinction between elementary and higher mental functions. Vygotsky interested in examining specific mental functions such as memory, perception, thinking, and their transformations from elementary forms to higher forms. Vygotsky put a distinction between the natural development incorporating elementary mental functions and social-cultural-historical-contextual development that transforms individual cognition (elementary mental functioning) into higher mental forms (Vygotsky, 1978).

As Vygotsky (1978) discussed "we shall call the first structures elementary; they are psychological wholes, conditioned chiefly by biological determinants. The latter structures which emerge in the process of cultural development are called higher structures. The initial stage is followed by that first structure's destruction, reconstruction, and transition to

structures of higher type. Unlike the direct, reactive processes, these latter structures are constructed on the basis of the use of signs and tools” (p. 124).

Based upon these two aspects of cognition; elementary (individual) and higher (social), Vygotsky (1978) offered a two-stage transformation to describe a generic cognitive process by which individuals internalize socially rehearsed ideas. This is called as *general genetic law of cultural development* and it signifies that “every function in the child’s cultural development appears twice, on two levels: first on the social, and later on the psychological level; first between people as an interpsychological category and then inside the child as an intrapsychological category. This applies equally to voluntary attention, to logical memory and to the formation of concepts. The actual relations between human individuals underlie all higher functions (Vygotsky, 1978, p.128).”

In Vygotskian perspective, meaning making of a (science) phenomenon can be attained in two planes (Vygotsky, 1978): interpsychological (social plane) and intrapsychological (cognitive plane). On interpsychological plane, the science teacher and students can rehearse and perform various social languages (Bakhtin, 1986) through diverse semiotic mechanisms (symbols, diagrams, graphics, gestures, intonations, and mimicking, etc.) as in the forms of speech genres (Wertsch, 1991). On the intrapsychological plane, individual thinking; as the appropriation of the previously negotiated concepts for constructing individualised schemes is performed (Vygotsky, 1978). This process is called as internalisation in which each individual generates a specific and more relevant version of ideas under negotiation for individual purposes.

Bakhtin’s Notion of Social Language

Bakhtin (1986) enlarged the Vygotskian perspective by emphasizing on the social language in terms of learning and teaching. Bakhtin (1986) defined social language as “a discourse peculiar to a specific stratum of society (professional, age group, and so forth) within a given system at a given time” (Holquist ve Emerson 1981, p. 430). *Stratum of society* refers to communities of children, scientists, teachers or any other specific group of learners or thinkers and talkers. To put it differently, a social language is a generation of discourse among persons to create meaning of natural or social phenomena that can be used for particular purposes by a specific learning group (Bakhtin, 1934). According to Bakhtin (1986) different groups therefore may use different social languages servicing diversified social and intellectual purposes.

The existence of a social language implies that same phenomenon can be conceived in different ways by people. For instance, a solid-state physicist enacts a distinctive social language when thinking and talking about the *sand*. A potter’s social language as he enacts for thinking and talking about the sand differs from the social language of the physicist (Scott, 1997; 1998; Leach & Scott, 2002). In both cases, the existence of the sand within physical world influence the ways of thinking and talking of the physicists and potters.

For instance, the physicists may understand the solid structure of the sand through experiments and use specialised terminologies and jargons to define their experimental settings, results, data, and evidences. On the other hand, the potter displays a divergent way of thinking and talking style about the sand. The potter has artistic design concerns when he thinks and talks about how he would shape a beautiful jug by using up the sand. An implication of social language phenomenon in the sense of the current study is that there is an inherent relation between thought (thinking) and language (talking) or discourse (language) and cognition (thought). In other words, the ways of our thinking systems truly define our talking styles (Bakhtin, 1986; Leach & Scott, 2002; Mortimer & Scott, 2003; Vygotsky, 1987; Scott, 1998; Wertsch, 1991).

Bakhtin’s Notion of Speech Genres

The concept of social language is elaborated by considering the speech genres (Bakhtin, 1934, Wertsch, 1991). Speech genres are not the formations of the spoken language. However, they are typical forms of utterances as the fundamental unit of verbal communication (Bakhtin,

1934). Speech genres are semiotic mechanisms to communicate within a social language (Bakhtin, 1934; Wertsch, 1991).

A social language incorporates speech genres such as graphs, tables, figures, gestures, symbols, stances, mimics, formulas, etc. Within instructional settings, different social languages are performed through varying speech genres. Differentiated social languages and speech genres are introduced by teachers and rehearsed by students on the social (interpsychological) plane of classroom. Then, learners will be able to advance a wide range or genre of distinctive types of talking (discourse) and thinking (cognition) styles (Leach & Scott, 2002; Scott, 1997, 1998).

Types of talking and thinking are then internalised and appropriated by individuals that make them personal and private for individualistic cognitive purposes. In other words, as Scott (1997) defines for learning science students have to use and adopt different social languages and accompanying semiotic mechanisms as in the form of speech genres. All these are language-based tools and scaffold mediated learning. These language-based tools are the social carriers of a world of meanings that are external to students. Semiotic mediation is central to all facets of knowledge co-construction (Wertsch, 1991). According to Vygotsky (1981), semiotic mechanisms mediate or attach social and individual aspects of concept formation, and connect the external and the internal, the social and the individual (Scott, 1997; Wertsch, 1991)

Learning Science in Vygotskian Sense

Regarding the acquisition of any science concept, Vygotsky (1987) attributed to *spontaneous concepts* and *scientific concepts*. Vygotsky asserted that “spontaneous concepts are developed through everyday experience and communication and are formed aside from any process aimed specifically at mastering them” (Scott, 1997, p. 16). However, scientific concepts are enhanced through deliberate and purposeful instruction as “the birth of the scientific concept begins not with an immediate encounter with things but with a mediated relationship to the object” (Vygotsky, 1987, p. 219).

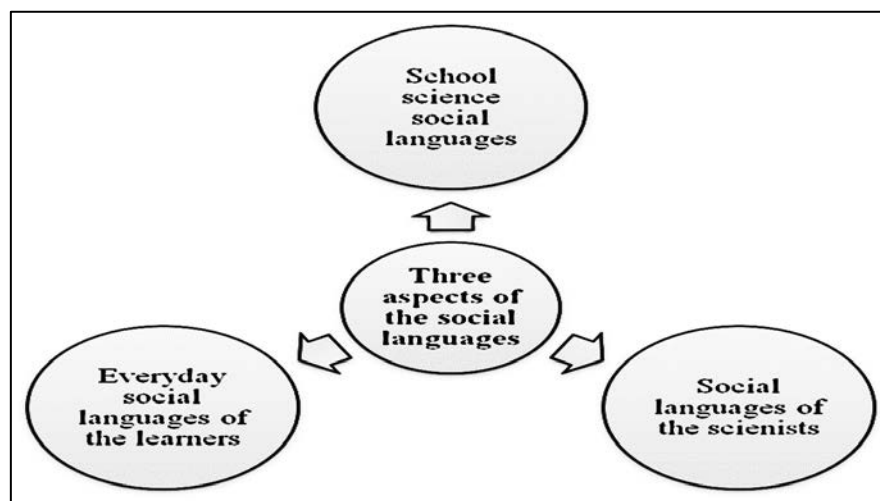


FIGURE 1. *Types of social languages in the context of Vygotskian teaching (adapted from Mortimer & Scott, 2003)*

In an instructional setting, in the context of learning and teaching science, there are three social languages represented in Figure 1. These are everyday social languages of learners, social languages of scientists and social languages of school science (Leach & Scott, 1995; 1999; 2000; 2002; Mortimer & Scott, 2003; Scott, 1997; 1998). Everyday social languages of learners are described as their spontaneous concepts (Vygotsky, 1987). These are developed and used by individuals to make sense of the events occurring around them.

For instance, an individual may be of the idea that *plants feed from soil*. This observation-based inference can be considered as a misconception *or* alternative conception. Alternative conceptions, in the first stage, can be seen as equal to misconceptions. However, in Vygotskian sense, an alternative conception of an individual cannot be matched with misconception of the phenomenon. To illustrate, scientists have their specific ways of thinking and talking styles for their specific purposes in generating scientific knowledge. Thus, scientists' different ways of thinking and talking are *alternative* to the individuals' everyday thinking and talking (Leach & Scott, 1995, 1999, 2000, 2002; Mortimer & Scott, 2003; Scott, 1997, 1998; Vygotsky, 1987). This implies that in the schools we as educators present a distinctive thinking and talking systems or social languages that are alternative to the individuals' everyday social languages.

Apart from these two social languages, there is another thinking and talking system labelled as school science social languages. This typology favours and features the social languages of scientists. This social language, on the other hand, is more pedagogically-oriented and structured around a curricular perspective by teaching of particular topics while eliminating others. Below-located examples (i.e., examples-1, example-2 and example-3) make the above-mentioned explanations between the social languages more apprehensible.

Example-1: A solid-state physicist considers a piece of the glass by attributing to the intermolecular forces and interactions among these forces. A glass blower considers the artistic aspects of the vitreous handcrafts. For the solid-state physicist and glass blower, the realities of glass within social, cultural, historical and contextual world influence the ways of thinking and talking of them. The former discerns the glass through scientific experimenting accompanied particular discourses (states of matter, intermolecular forces, atoms, etc.). The latter will attach importance to how glass blowing should be undertaken to design unique creations since he has artistic design concerns when thinking about how to shape the glasses aesthetically by applying specific glass-blowing techniques. This example directly reveals the intimate relation between thought (ways of thinking) and language (ways of talking). This instance was structured based on the ideas of Leach and Scott (2002).

Example-2: When drinking orange juice, an individual may interpret this acting as sucking a bottle of orange juice with a straw. However, scientists have a dramatically dissimilar social language in interpreting the same event. Scientists think and talk about drinking orange juice through principles of air pressure and fluid mechanics: volume of the straw and density of orange juice. This instance implies that social languages of scientists may greatly differ from the everyday social languages of individuals. In this context, learning science concepts can be considered as acquiring the thinking and talking systems of the scientists. To put it differently, science learning requires "enculturation through language to the concepts and modes of reasoning of the scientific community. Any individual who wishes to gain access to scientific knowledge can only do so through interaction with those who are familiar with that knowledge." (Scott, 1997, p. 15). This instance was structured based on the interpretations of Scott (1997).

Example-3: Individuals can utter such expressions: "Plants feed on the earth." or "I've consumed my energy today." Both articulations are far from being scientifically appropriate. However, individuals, using this everyday externalisation, can express the occurrences in their environment in this way and do not feel uncomfortable about this. This is because the individuals have observed plants in soil. When they add some nutrients such as water to the soil, and then the plant draws up the nutrients through its roots and grows.

Moreover, when an individual becomes tired after playing tag, he can think that the activity is energy consuming. For the first instance, an expert in plant physiology will account for the feeding of plants by photosynthesis through chemical equations displaying a distinctive jargon. For the second example, an expert in biological energy systems can explain the observation of feeling tired by taking the energy transformations (aerobic respiration, consuming and producing ATP) into consideration. This instance was structured based on the interpretations of Leach and Scott (2003).

As a whole, in Vygotskian perspective, as represented in the above-located illustrations, there is a close and reciprocal relation and determination between thinking and talking systems of the different learner groups. To be clear, individuals' thinking styles determine their talking typologies that may inherently incorporate distinctive vocabularies, terminologies or jargons. Thus, if individuals are engaged in the thinking systems of the scientific community, they would be comfortably operating scientists' social languages. This also implies that science learning in schools incorporates comprehending, appropriating and internalising thinking and talking styles of a specific community in which experts develop and enact an array of distinguished or alternative social languages.

Science Teaching in Vygotskian Sense

Science teaching in the Vygotskian perspective is directly associated with the term Zone of the Proximal Development (ZPD). The ZPD signifies "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable other" (Vygotsky, 1978, p. 86). Indeed, the ZPD defines a consciousness and control while acting a higher mental process (e.g., concept learning, inductive reasoning, and deductive reasoning). This control (regulation of the mental states) and consciousness are seen at a later stage of development of any mental function (Vygotsky, 1934, p. 90).

According to Bruner (1985), a more knowledgeable other who "serves the learner as a vicarious form of consciousness until such a time as the learner is able to master his own action through his own consciousness and control." (p. 24). In progress of time, individuals reach the required consciousness and control during acquiring new mental functions *or* conceptualizations. Beyond, individuals can use newly being acquired thinking (consciousness) that is attained by deliberate scaffolding of more knowledgeable/capable others within the ZPD of a learner. In other words, "the tutor in effect performs the critical function of "scaffolding" the learning task to make it possible for the child to internalize external knowledge and convert it into a tool for conscious control." (Bruner, 1985, p. 25). As a whole, a less capable other (e.g., pupils) borrows a version of conscious awareness from a more knowledgeable other (e.g., teachers, parents, etc.) until the time he is able to carry out the targeted behaviour or action alone that is detailed in the below-located sections.

According to Scott (1998), "the concept of scaffolding relates closely to the zone of proximal development in specifying the kinds of support which a tutor might provide to assist a learner in completing a particular task for the first time and thereby developing the competence to perform the task independently." (p. 69). Mercer (1995) clarified the scaffolding phenomenon as a sensitive and supportive intervention of teachers as more knowledgeable/capable others for the sake of learners who may not be able to manage and handle a required performance alone. Scaffolding incorporates a harmony as Mercer (1995) stressed that "the provision of guidance and support which is increased or withdrawn in response to the developing competence of the learner." (p. 75). To be clear, on one hand, scaffolding includes a gradual withdrawal of assistance, on the other hand, a gradual handover of responsibility of the task from teacher to student.

Furthermore, responsiveness is central to the scaffolding (Clarà, 2017; John-Steiner & Mahn, 1996; Scott, 1997; 1998). Within the ZPD of a student, teachers may be responsive to divergences between the present level of the student performance and the level of the performance that was previously specified by the learning purposes (Chaiklin, 2003; Scott, 1998). Chaiklin (2003), Gredler (2012) and Scott (1997) elucidated the responsiveness through three pedagogical elements: *monitoring, analysing and assisting*. Monitoring specifies that the teacher follows the students' present performance. Analysing aims at deciding the differences between present performance of the student (*actual* performance) and the target performance for the student (*potential* performance). Assisting clarifies that teachers' responses to the inherent differences between the students' actual performance(s) and potential or goal performance(s).

There are two means of assisting a goal performance: *pedagogical* and *instructional*. Particularly Scott (1998) emphasized in the context of teaching science that “in taking action to assist the student in moving towards the target performance, the teacher might employ pedagogical means and/or instructional means. Pedagogical means consist of the discursive interventions made by the teacher in spontaneous response to the student's performance; instructional means are the teaching activities which are planned ahead of the instruction.” (p. 70). In this study, only instructional means of responsiveness are taken into account to inform the Vygotskian science teaching.

Learning Demand

Another phenomenon considered in the current study is the *learning demand*. This concept was first proposed by Leach and Scott (2002) to offer a way of appraising the differences between the social languages of the school science and social languages that students bring to classroom. The learning demand is more about the communalities and differences between *social languages of school science* and *everyday social languages of students*. Teachers use textbooks, curriculums, and their own subject matter knowledge bases, instructional materials by infusing a social language that is spoken only in schools and labelled as social languages of school science.

Social languages of school science are mostly alternative to students' everyday social languages. There is an expected difference between the social languages of school science and learners' everyday social languages. Indeed, the distance between these two social languages determines the amount of the learning demand. For instance, in an elementary science curriculum, there are various science contents accompanied by concrete outcomes that can be reclassified in terms of expected learning demands. Actually, when learning demand is greater or when there is less communality or more differences between social languages of school science and everyday social languages of students, there would be more dialogic space on the side of teacher for initiating and maintaining social negotiations of the meanings.

To put it differently, when distinctiveness between two social languages is larger, this would permit science teachers to trigger and sustain a more evaluative or argumentative instructional streaming. On the other hand, there may be curricular science contents that may be parallelized and communized with the individuals' everyday social languages. To explicate, thinking and talking systems of students can be closer to thinking and talking systems embedded in the school science. In this case, there is less dialogic space for science teachers to initiate, maintain and finalise a rigorous social negotiation of meanings. Therefore, it would be more plausible to share science contents to students by, for instance, direct lecturing, in the presence of narrower learning demand. More concrete examples detailed below will illuminate the point.

Identifying Learning Demand

Particularly for science concepts, there may be great learning demands on the side of the students. For science teaching, learning demand can be categorized into three themes: *conceptual*, *epistemological* and *ontological* (Leach & Scott, 2002; see also Figure 2). These themes are instrumental in planning and designing science teaching sequences. For example, regarding *conceptual tools*, students may suppose that *forces have actions on the objects by either pulling or pushing them*. However, there may be cases where a certain amount of force is not able to push or pull a heavier or fixed object. In this case, learning demand can be expected as higher.

To illustrate, there is a *confliction* or *challenge* within students' prior reasoning pertaining pulling/pushing actions of the force. For another example, the teacher may present an idea that if substances incorporate atoms and if someone holds a pen as a substance, he touches the atoms of the pen. Presumably, students will not accept this proposition and find it

considerably disturbing since they already have supposed that atoms are embedded in the substances. These examples show the differences between the social languages of science and students' everyday social languages. When these cases or topics are under consideration, there will be ascending learning demand on the side of students and this allows teachers to create and maintain yielding social negotiations of the meanings. To explicate, increasing learning demand guide science teachers to initiate and maintain an internally persuasive array of dialogues to convince students that there may be alternative and more explanatory social languages than their alternate meaning positions.

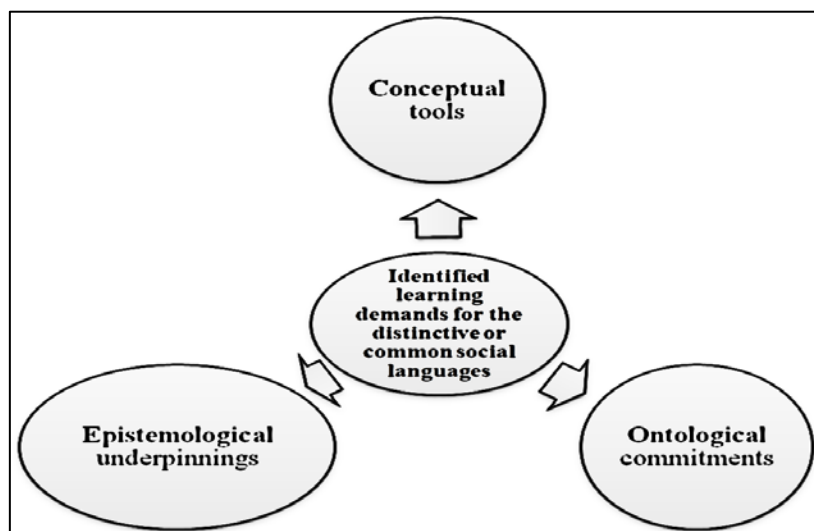


FIGURE 2. *Different aspects of the learning demand*

Many *epistemological underpinnings* of scientific revelations are absent within everyday social languages of learners (Chinn & Brewer, 1993b; Duit & Treagust, 1998). By exposing to the school science social languages, students are required to display several reasoning and practical skills, for instance, collecting, analysing and interpreting valid and reliable data as the indicators of the epistemologically-oriented learning demands. To illuminate, during an experimental process, students have to determine the ways in which they will be able to collect and analyse data in a reliable and valid manner in responding to their research questions. Various additional examples of epistemological learning demands can be listed as:

- developing experimental strategies (Crawford, 2000),
- modelling and rehearsing aspects of processes of science (McMahon, 2012),
- learning about scientific work (Crawford, 2000; McMahon, 2012),
- showing the attitudes and attributes of scientists by example (Crawford, 2000),
- multimodal thinking (Chin, 2007),
- justifying and evidencing (Simon, Erduran & Osborne, 2006).

These are heuristic actions of scientific communities and students should perceive these practices unfamiliar and cognitively challenging; in turn, there will be augmenting and epistemologically-oriented learning demands on the side of the students. To support, when students try to act the above-listed science process skills, in an implicit sense, they will respond to particular questions such as “what we know?”, “how do we know?”, “why do we believe?” or “how do we know what we know?” These are related with the epistemological constructs of scientific idea production processes that have to be exercised by students in the classroom. However, students may have intuitive reasoning tendencies instead of gathering and analysing data in reacting to a case by displaying a rationalist and empiricist reasoning.

In this context, for instance, during an in-class science inquiry activity, a student can be asked to make observations or measurements more than 10 times to attain more reliable data set. Herein, the important point is not to guide students to make observations for many times to be reliable in idea sharing based on the data sets. Beyond, the purpose of this guidance of science teachers should be understood in the way that students have to comprehend the fact that why, how and to what extent increasing frequencies of the observations makes the gathered data more credible, dependable and defensible. This is acknowledged as an epistemological interrogation creating a substantial learning demand on the side of the students.

There are concepts of science for which experts' *process views* are incommensurable with the students' *materialistic views* (Chi, 2008). When this is the case, learning demand is readjusted in an ontological perspective. To be clear, learners should shift their thinking system from a materialistic view to a process view. For instance, "two candidates for these types of change are heat, which needs to change from a flowing fluid to energy in transit, and a gene, which needs to change from an inherited object to a biochemical process." (Fraser, Tobin & McRobbie, 2012, p. 109).

As Fraser et al. (2012) proposed, there are science concepts to force students to revise, modify, expand or totally shift their ontological commitments and this generates greater learning demand on the side of the students. For instance, students may talk about the existence of the spaces among molecules to categorise states of matter. A teacher may propose that if molecules incorporate spaces that students believe in, what other stuff or things could fill or infuse these spaces or as a more triggering interrogation, what is the substance or stuff that could fill the spaces in an atom? Similar science phenomena may compel students to make ontological readjustments forming ontologically-oriented learning demands.

There are of course curricular contents requiring lower levels of learning demands on the side of the students. The curricular contents requiring descending learning demands may not give instructional chances to science teachers to create and maintain in-class social negotiations of meanings. Having had more communalities between the school science social languages and students' everyday social languages will lead to the adoption of more monologic approaches. An example can be sharing the content regarding human skeleton system incorporating labels, formations and quantities of bones in a human body. For this content, it is more probable to lecture or transfer the content directly and explicitly to students. Because, there is equally no or little linguistic or conceptual distinction between school science social languages and everyday social languages of learners in acquiring the bones within human skeleton system.

In summary, in Vygotskian perspective, there are featured conceptions (e.g. social languages, speech genres, learning demand, scaffolding, responsiveness, and social negotiations of meanings) that inform classroom (instructional) practices and one of them is interpreted in this study through the rest of the paper. The next section introduces two aspects of teaching and learning science in Vygotskian perspective: *pedagogical preparation for the social negotiations of meanings* and *the in-class enactments of the social negotiations of meanings*.

A Thinking Tool for Preparing Science Teachers for Exclusively Mutual Social Languages

It would not be credible to directly inject the Vygotskian perspective into the classroom context without making substantial instructional modifications on it (Scott, 1997). At the outset, therefore, presumable curricular contents and structural and emergent qualities of classroom talks should be considered seriously to prepare a science subject teaching flow within the context of the Vygotskian perspective. To be clear, Vygotsky did not generate his ideas for teaching science contents in the school as he proposed more generic assertions that should be modified for rearranging the core components of his propositions for the sake of teaching science effectively (Soysal, 2017; 2018).

Essentially, Vygotskian teaching incorporates *social negotiation of meaning* requiring discursive cycles for meaning making in the science classroom. This signifies that *individualised*

meaning making (intramental plane) is a *socialised* dialogic (intermental) process (Mortimer & Scott, 2003). Social-intellectual interactions and exchanges among the peer community are important in learning and teaching school science in the context of the Vygotskian perspective. Vygotsky proposed a *learning-driven cognitive development* (John-Steiner & Mahn, 1996) as from intermental plane to intramental plane. Thus, in the current study, there is an explicit emphasis on the social negotiation of meaning. The term *negotiation* is also featured since Vygotsky refined development as the transformation of socially shared activities into internalised ones. Once individuals externalise their ideas for the evaluation, judgement, criticism and legitimation of others, every individual would have a chance of transcending his conceptual limits by transforming others' pre-structured mental schemes. This requires conceptual, epistemological and ontological negotiation of a meaning by which individuals' pre-determined mental schemes are modified, revised, expanded, or totally altered into new and more meaningful structures by others. In the Vygotskian perspective, this signifies that through others we become ourselves.

Scott (1997) proposed some adaptive pedagogic strategies to transform the Vygotskian concepts for teaching science at the level of secondary school. Leach and Scott (2002) then improved the scope of the Scott's (1997) propositions by introducing a *four-step preparation tool* (Figure 3) for science teachers in teaching science by favouring and featuring the Vygotskian perspective.

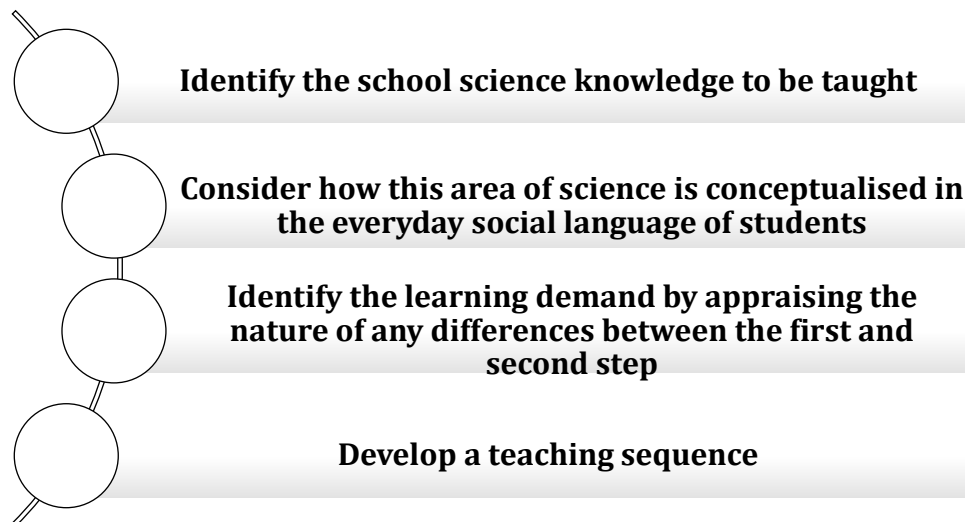


FIGURE 3. A thinking tool for preparing a science teacher for the contradictory social languages

First step: Identify school science knowledge to be taught

In the first step, science teachers should identify and clarify the school science to be taught or accompanied social languages of the school science. A planned and organised selection or re-categorisation of the topics embedded in the available curriculum must specify details and justifications of that intentional selection or *discernment* a topic from other(s). On one hand, in science curriculum(s), there may be topics requiring rigorous or higher-order social negotiation of meaning. This implies that some curricular topics can be more “discussable” (van der Veen et al., 2015). Injecting the discussable topics into classroom negotiations is an indicator of productive classroom talks or discourses (van der Veen et al., 2015).

By the term discussable, in the current study, it is intended that the topic has to grasp the group's temporary focus of attention by giving direction, purpose and duration to the talks (Doblaev, 1984; van Oers, 2012). The discussable topic clarifies that students will engage in the processes of social negotiation of meaning not for the purpose of just dialoguing (or philosophizing) for the sake of dialoguing. Thus, science teachers must strategically discern

discussable topics that determine what can be proposed about this topic within the context of a specific classroom dialogue (van der Veen et al., 2015). On the other hand, there are other topics in the curriculum that may be less discussable and can be directly transferred to students. Thus, through operating a *semipermeable discursive-pedagogical lens*, science teachers should look into the curricular contents and discern a specific content from others regarding the selected topic's *serviceability* in creating discourse opportunities for establishing classroom contexts allowing for authentic social negotiation of meaning. Thus, science teachers should be plausible in discerning, classifying or sorting out curricular contents regarding the *distances* or *communalities* between social languages of school science and everyday social languages of students.

Second step: *Identifying how a specific topic of science is conceptualised in the everyday social language of students*

According to Ford (2008; 2012), critiquing ideas in the classroom may be one of the influential ways of teaching and learning science concepts. Once students feel themselves unsatisfactorily against the critiques proposed by other members of the community, this may bring about a conceptual alteration or expansion on the side of the students (Ford, 2008; 2012). Students may use comfortably their everyday social languages for explicating the natural events occurring around them. However, student-led thinking and talking systems may be less elucidatory compared to the deeper and evidential social languages of expert community.

In this context, the responsibility of science teachers is not to falsify students. It should be recommended that science teachers have to initiate and maintain an internally persuasive dialoguing among the peer community to concretely show that there may be alternative thinking and talking systems that can be more powerful than their own and everyday one in accounting for natural phenomenon. Thus, it is strictly suggested that every in-class discursive journey should be initiated by taking the individuals' everyday social languages' content into account. In other words, science teachers must use the student-led information to continuously re-structure the streaming of classroom discourse by unfolding students' utterances.

For ensuring and sustaining academic rigor in the classroom discourse, science teachers should locate challenging dialogues among the peer community. When there is a rigorous debater, discussant or negotiator (the science teacher) in the science classroom, students would notice their less elucidatory social languages, eventually they will try to resolve this incompleteness through data collection, analysis and interpretation since their initially oriented hypothetical reasoning is not addressed the challenges proposed by the science teacher. Thus, the second step requires determining how students have conceptualised science topics within their own social language system.

The second step includes crystallising the alternative conceptualisations, reasoning, claims and assertions of the students that may be greatly differed from the school science social languages. For instance, for force and motion phenomena, students may be of the idea that heavier objects reach to ground faster than lighter ones if they are dropped at the same time from the equal height. Students may think in the way mentioned above since they suppose that gravitationally, earth pulls the heavier one more than the lighter one, then, this will accelerate the heavier one more than the lighter one, and the heavier one hits the ground in a shorter time than the other.

In scientific terms, it is well known that objects with equal volumes reach to ground simultaneously if they drop at the same time from the equal height, in the same physical environment and if the objects have similar geometrical shapes. Having an understanding regarding mentioned student-led alternative explanation system about force and motion phenomena will be informative for science teachers to generate discursive opportunities for students to re-consider their thinking and talking systems, in turn, revise or totally shift them. A source for science teachers to investigate the student-led incomplete and/or fallacious talking and thinking can be the cumulative scholarly-based literature regarding alternative conceptions in science education. By considering this literature, a teacher can analyse research-based

student-led alternating thinking about science concepts. Examples from the mentioned literature will be provided in the next step.

Third step: *Identifying learning demand by appraising nature of differences between social languages*

The Step-1 and Step-2 provide analytical aspects of concrete differences between different social languages. The Step-3 services clarifying magnitude of the learning demands on the side of students. In this step, science teachers should tackle with three layers of the learning demands (distances between the social languages): conceptual, epistemological and ontological.

Identifying conceptual contradictions: For instance, students may be confused regarding heat and temperature concepts. Mostly, students may use these terms interchangeably in the classroom or in their daily life. At this point, science teachers should pose a series of questions about heat and temperature concepts. For instance, students are aware that they cannot touch a candle when it is lightning since it is too hot. Students can easily touch an active radiator core located in their classroom. Students also observe that a lightening candle cannot warm up the classroom in a winter day.

A radiator core with *lower temperature* compare to a lightening candle can heat up the classroom in a winter day. In this example, there is therefore an explicit cognitive challenge for students as they have to resolve this dilemma by attributing to the differences and communalities between the heat and temperature concepts. As a whole, students will expand, modify or change their conceptual schemes in order to shed light on the above-mentioned dilemma. In conclusion, it can be inferred from the above-mentioned example that there may be greater learning demands on the side of students when they are engaged in classroom talks pertaining heat and temperature concepts.

Determining ontological contradictions: In scientific terms, ontologically, the heat concept is defined as a *thermal process* not a *thermal entity*. In other words, the heat exceeds the limits of a system and it is acknowledged as thermal fluid. Thus, transfer of the heat occurs continuously from a system to another. In molecular scale, there is always a thermal activity or transfer of energy from one particle to another within and/or between all substances. However, students may perceive the heat as an entity instead of an ongoing and eternal process or they can conceive the heat phenomenon as a substantive and easily measured entity (Mortimer, 1995). It is therefore inferred that due to the differences between prescriptive student-led materialistic ontological commitments and experts' process views of the heat phenomenon, there will be a greater learning demand on students.

Capturing epistemological contradictions: How do we know that the heat (energy) is transferred from one particle to another within deep or internal areas of a substance? How could we observe this? Could we observe this? Is it measurable (substantive) with man-made tools? How we create reliable tools to measure heat transfer or degree of temperature? These questionings will be thought-provoking for students and produce greater learning demands on them. Students must develop a specific vision for dealing with the measurement of the heat and temperature within a system.

To explicate, students must develop a novel thinking and talking system by linking *micro* and *macro* perspective of substances. For instance, to comprehend the working mechanism of a thermometer, students must consider the changes in the micro scale and their reflections to the macro scale (Gilbert & Treagust, 2009; Talanquer, 2011). However, this strictly requires an epistemological transformation of students' pre-determined mental structures (e.g., mostly accounting for the dilation phenomenon by attributing to the macro specifications of substances) into more sophisticated ones (Johnstone, 1982; 1991). In the case of accounting for the working mechanism of the thermometer, students have to make concrete linkages between the micro (e.g., molecular or atomic interactions) and macro worlds (e.g., observational or phenomenal changes in the volume of an object during heating up it) of substances (Johnstone, 1993; 2000).

In summary, as detailed above, science teachers should find out the amounts of the conceptual, ontological and epistemological learning demands of students regarding curricular

science topics by operating three steps by an integrating purpose. Generally speaking, this requires a novel pedagogic lens enabling *reading the science curriculum in a different way*. To explain, science teachers should reorganise the curricular outcomes by calibrating them according to their presumable and potential learning demands on students.

A model of the in-class implementation centralising the social negotiation of meaning

In this section, a model of the in-class implementation centralising the social negotiation of meaning regarding teaching science topics are presented and exemplified. In order to frame the exemplification, Engle and Conant's (2002) ideas regarding guiding principles for fostering productive disciplinary engagement were considered and applied. Engle and Conant (2002) proposed four phases for fostering community of learners.

These are (i) problematizing, (ii) authority, (iii) accountability and (iv) resources. By problematizing, Engle and Conant (2002) proposed that students are encouraged to take on intellectual problems (p. 400). In the current study, this refers that students may have alternate thinking and talking systems that may be contradicted with social languages of school science. When this is the case, there will be intellectual problems for students to cope with since teacher-proposed alternative points of views may not be explained by students' everyday social languages.

By authority, Engle and Conant (2002) stated that students are given authority in addressing such problems (p. 400). In the context of the present study, this means that students engage in data collection, analysis and interpretation processes to test their initially-oriented hypothetical assertions to resolve their dilemmas that can be conceptual, epistemological or ontological mentioned above. Thus, students will have chance of testing their ideas (senses) against a more formalised and concrete system of logic (meaning making).

By accountability, Engle and Conant (2002) indicated that students' intellectual work is made accountable to others and to disciplinary norms (p. 401). In the perspective of the current study, this item refers that by student-student interactions and exchanges, students will try to persuade others holding an alternate explication system that their argumentations are more credible, reliable and valid to account for a science phenomenon under consideration. By resources, Engle and Conant (2002) advocated the idea that students are provided with sufficient resources to do all of the above (p. 401). Based on the four-facet model of Engle and Conant (2002) and Vygotskian ideas represented above, in the current study, a combined model of teaching sequence is proposed, and it is displayed in Figure 4.

As presented in Figure 4, there are three cycles of the proposed model of teaching sequence. These are intertwined cycles: (i) *initial social negotiations of meanings*, (ii) *experimenting for internalising*, (iii) *whole group negotiations*. All phases incorporate iterative and overlapped stages of meaning-making processes: "confliction", "negotiation" and "consensus". To explicate, teacher and students must engage in a series of *posing-recognising contradictions (the role of the teacher)* and *negotiating-resolving the contradictions (the role of the students)* for an authentic verbal exchange. These processes require redefining, re-comprehending and practising thought and language (in) consistencies (Vygotsky 1962; 1978; 1981). All stages of the teaching sequence are elaborated and framed below.

First Stage: Initial Social Negotiations of Meanings

In this phase, science teachers initiate rigorous in-class discussions through an array of questioning-based discursive exchanges that may be thought-provoking. Moreover, this phase may also be launched through attractive instructional demonstrations incorporating unexpected and contradictory results for students. The teacher-led questionings or demonstrations may be serviceable to show students their ideas about a science concept can be less explanatory or incomplete.

To put it differently, teacher-led challenging articulations or demonstrations guide students to think that they may hold conceptual, epistemological or ontological conflictions regarding the

topic under discussion that should be modified or completely altered. This phase is equal to *the problematizing* in which students take on intellectual problems since there is an unexplained science phenomenon waiting for the resolution. One of the productive ways of resolving a cognitive contradiction is to gather, analyse and interpret data to detect the details of a natural phenomenon. Thus, once conceptually challenged, in order to avoid intuitive reasoning and locating evidence-based arguments, students may re-consider their cognitive contradictions in experimental settings to detect another thinking and talking system that may favour and feature social languages of school science. Discursive responsibilities of science teachers in this stage is to

- listen actively and comprehend students' utterances,
- invite students to elaborate on their underlying meaning positions and make their thinking fallacies explicit and public,
- pose scaffolding questions to aid students in gradually adopting an alternative thinking and talking system.

In the end of the beginning discussions, students are allowed to design their own research questions. The student-proposed questions are based upon the contents of the discussions among the peer community. For instance, after discussing many aspects of an objects' motions on an inclined plane, students may be asked to propose presumable variables determining the arriving time of different objects to the bottom of the inclined plane.

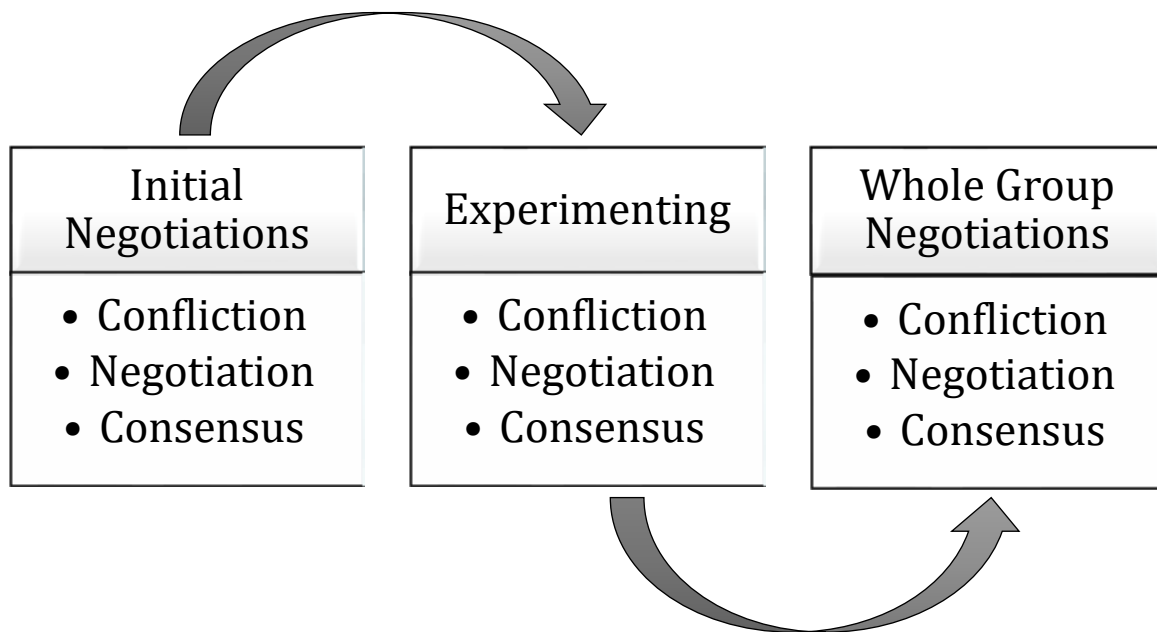


FIGURE 4. *The discursive cycles of the social negotiations of meanings (structured originally in the present study)*

Second Stage: Experimenting for Internalising the Being Negotiated Content

In the experimenting phase, students try to gather data and involve in data analysis and interpretation processes to generate evidences as arguments to support or change their hypothetical claims. Discursive quality of the next phase (whole group negotiations) is greatly based on the diversity and quality of student-led research questions. This phase is associated with Engle and Conant's (2002) authority term by which students are assigned as the epistemic

authorities in addressing research questions they design. In experimenting phase, teachers should scaffold students to redefine and, if it is needed, re-construct their research questions.

To support, some student groups may not be able to compose questions by explicitly inserting research variables. Moreover, student groups may have tendencies in exploring similar research questions incorporating same variables. Science teachers, at that point, must make a variation in the questions of the groups through guiding students to research into alternative variables to enlarge the scope of further in-class negotiations (Cavagnetto, 2010; Cavagnetto & Hand, 2012). Students may also be liable to examine only one variable ignoring other competing variables (moderator variables) during experimenting phase. However, a powerful and productive experimenting requires multivariable reasoning (Kuhn, 2007).

During experimenting, for instance, a student group may decide to compare arriving times of two differently weighted masses to the bottom of an inclined plane. This group, as inferred, considers only the mass variable. Science teachers therefore must direct students to examine, for example, the *height of inclined plane* or *inclination angle* as a competing (secondary or moderator) variable in addition to mass difference variable in shedding light on the more aspects of the phenomenon by allowing for multivariable reasoning. In this stage, teachers should also aid students when they face with experimental obstacles. In this phase, students may be in need of special helps in comprehending pre-requirements of experiential procedures. Presumably, students may not have an understanding pertaining dependable measurements. To compensate this, science teacher may ask students to make their observations more than one time or at least five times to have reliable measurements.

In this context, for *internalisation* or *appropriation* of experimental procedures on the intra-psychological plane, teachers may provide *individual-based* or *one-to-one scaffolding* to students. As mentioned, in the sense of *responsiveness*, at the outset, science teachers have to analyse the amount of the necessary instructional aiding by monitoring students who may not be able to attain reliable and valid measurements when they collect observational data by using an experimental design incorporating a mass moving on an inclined plane.

Third Stage: Whole Group Social Negotiations of the Meanings

During this stage, student groups introduce and argue about their experimental findings. First, science teachers should invite groups for their presentations *with a specific order*. To advocate, main purpose of whole group negotiation is to raise the breadth of student-student discursive interactions and exchanges through comparing and contrasting distinctive student-led data-based inferences. Presumptive discrepancies between student-led data-based results should be therefore detected and recorded by teachers to extend the breadth of intellectual interactions among the peer community. Once students present their experimental inferences, teachers should invite other students to criticise, evaluate, judge and legitimate their classmates' arguments by asking questions and providing suggestions. This teacher-led attempt facilitates student-led critical evaluations of the presented predicates by intellectual efforts of students (van Zee & Minstrell, 1997a; 1997b).

Student groups legitimate each other pertaining relevancy of research questions, reliability and validity of data collection procedures, linkage between data gathering, interpretation and purpose(s) of research questions, derived arguments from gathered data, or whether a group's evidences support their (initial) claim (Cavagnetto, 2010; Cavagnetto & Hand, 2012). In the perspective of Engle and Conant (2002), accountability should be featured in this phase in which students should be prompted to be accountable to others and to disciplinary norms. Moreover, for ensuring effective and intellectually contributing presentations, students should be guided to create, for instance, graphical representations to explicate their results healthily for external audits as their classmates. Science teachers should therefore require student groups intentionally to use different modes of semiotic mechanisms such as graphics, tables, drawings, etc. to explicate their overall results. This initiative of science teachers may gather students' attention regarding the value of communicating their ideas with other research groups as a fundamental exercise of the all professional scientific communities.

More importantly, science teachers should deliberately guide students to compare, for instance, two groups' results that may incorporate similar or close research questions but heterogeneous concluding remarks. When this is the case, different student groups try to resolve the heterogeneous conclusions by closely examining their classmates' experimental details and reasoning procedures by which inferences are generated. These in-class interactions may be considered as the richest moments where discursive interactions and exchanges between teacher and students are maximised allowing for productive classroom discourses.

Concluding Remarks

There are featured points obtained from the analysis of the Vygotskian teaching and learning. First, it is understood that science teachers have to manage a discursive journey from a social language (students' everyday social languages) to another (school science social languages) (McMahon, 2012). Thus, there will be a *pedagogical tension* on the side of science teachers when learning demand is greater (Scott et al., 2006; Soysal, 2018). Whilst science teachers must take student-led everyday social languages into account, they must maintain scientific story by introducing school science social languages. At this point, there are numerous questions to be raised:

- Which social languages of the different groups of learners should be prioritised by teachers during classroom discourse?
- Is there an order of importance between social languages of learner groups regarding the meaningful learning of science concepts?
- If a teacher starts by considering the everyday social languages of learners, what are the ways for her to maintain and finalise classroom discourse (discursive journey, a sequence of discourse) to recognise and appropriate an alternative thinking and talking system in the form of scientists' social languages or social languages of school science?

By keeping the above-listed questions in mind, original contribution of this study is that students may not be eager to revise or completely alter their everyday social languages into more formalised or technical entities favouring school science social languages. Thus, teachers should introduce school science social languages with a *critical stance* or *argumentative manner* that should be regulated by fine-grained social negotiations of meanings. This signifies that science teachers have to make *alternative* and *less useful everyday social languages of learners* obvious and noticeable to them (Chen et al., 2017).

To put it differently, teachers should show students that their available social languages may not be enough to explicate some contradictions emerged during social negotiations. Thus, teachers should convince students that they have to shift or expand their existing social languages or *thinking and talking systems* into another that is more powerful and functional in accounting for a science phenomenon under consideration. This type of transition from everyday social languages of individuals to school science social language is strictly required three principles crystallised in this study and supported by earlier studies:

- (i) *contradictory or challenging initial social negotiations of meanings,*
- (ii) *explicit and deliberate data collection, analysis and interpretation*
- (iii) *communicating ideas with others* (Chen, et al., 2017; Engle & Conant, 2002; Soysal & Radmard, 2018; Soysal & Yilmaz-Tuzun, 2019).

Table 1 displays different perspectives on *concept formation or conceptual change processes* of individuals particularly in the context of science teaching and learning processes. One of the most known and being studied model was proposed by Posner et al. (1982) in the name of *conceptual change theory*. Both Engle and Conant's (2002) model and this study's proposal incorporate communalities and differences with the model of Posner et al. (1982). As seen in Table 1, all instructional models advocate the idea that students should be dissatisfied with their existing conceptions or *everyday social languages*. According to Posner et al. (1982) after

any conceptual change, new conception should be comprehensible and credible to students who will be able to use the new conception fruitfully to explicate the natural phenomenon more effectively compared to prior schemes (everyday social languages of students). As it is known, Posner and colleagues (1982) featured a Piagetian theory of learning that is development-driven. To our knowledge, Piaget's psychological or cognitive constructivist assertions deal with meaning as constructed by *the individual* (Miller, 2002). Piaget (1971) theorized the sequence of cognitive stages that all human beings experience.

Table 1. A detailed comparison of different modes of teaching science around concept forming

Posner et al.'s (1982) model of conceptual change	Engle and Conant's (2002) four principles for fostering community of learners	This study's Vygotskian-based instructional model of concept formation
1. There must be dissatisfaction with existing conceptions.	1. Problematising: Students are encouraged to take on intellectual problems	1. Initial Social Negotiations of Meanings (contradictory or challenging social negotiations of meanings)
2. A new conception must be intelligible.	2. Authority: Students are given authority in addressing such problems	2. Experimenting for Internalising the Being Negotiated Content (explicit and deliberate data collection, analysis and interpretation)
3. A new conception must appear initially plausible.	3. Accountability: Students' intellectual work is made accountable to others and to disciplinary norms	3. Whole Group Social Negotiations of the Meanings (communicating ideas with others)
4. A new concept should suggest the possibility of a fruitful research program.	4. Resources: Students are provided with sufficient resources to do all of the above	

There was a special concern for Piaget. The logic as the very basic instrument to generate universal knowledge is not expected to be acquired directly from the social-cultural-historical-contextual environment. According to Piaget (1971), a person's knowledge comes from reflecting on and coordinating her own cognition or thought, but not from by mapping the external reality. Despite Piaget (1971) evaluated social environment as an important external factor, he never had the idea that social interactions are the main mechanism for changing thinking (Moshman, 1987). It is named as the first wave of constructivism as solo constructivism or Piagetian constructivism (Paris, Byrnes, & Paris, 2001).

As mentioned, in the current study, Vygotskian perspective is taken and a *learning-driven* cognitive or mental development is strictly accepted requiring the social-cultural-historical-contextual interactions and exchanges among peer communities or communities of learners (Engle & Conant, 2002). According to Vygotsky (1978, 1987), social interactions, cultural-historical tools and activities of the society shape individuals' cognition and learning. By engaging in a range of social activities with others, learners may select, appropriate and internalise the expected outcomes (phenomena) that are generated by thinking and talking together in a community (i.e., lab workers, classrooms, room of taxi drivers). This explicitly requires a *joint thinking and talking* process featuring social generation of higher-order mental functions (Mercer, 1995).

As a whole, this study's model of teaching sequence tries to improve the Piagetian-based conceptual change theory by adding social elements of cognitive development, learning and teaching processes. To support, as seen in Table 1 and detailed within above sections, the proposed model of teaching sequence emphasizes on the social-verbal interactions and exchanges among the peer community in which student-led propositions may be expanded, modified or totally shifted when students are allowed to make intellectual cognitive contributions to classroom discourses by criticising or legitimating their classmates ideas.

In addition, proponents of the conceptual change theory use *inorganic* refutation texts for persuading students to change their initial mental schemes that is either incomplete or totally fallacious. However, in the model of Engle and Conant (2002) and as adopted in this study's model, students are responsible to refine and purify their classmates' *fallacious (alternate)* ideas by undertaking data collection, analysis and interpretation processes as an *organic* process that is very similar to the fundamental practices of expert communities.

More importantly, this study also supports the idea that students may not quit their everyday social languages that are substantially functional in order to communicate with others in diversifying societal contexts. Proponents of the conceptual change theory see student-led fallacious thinking as *misconceptions*, but, in the current study, adopting the Vygotskian perspective, student-led fallacious thinking is acknowledged as *alternative conceptions* or thinking and talking systems that may be partially or totally different from the professionals' more formalised and technical social languages.

To be clear, this means that individuals have their own everyday social languages in explaining events occurring around them. The everyday social languages of learners are also crucial to successfully engage in daily life events such as purchasing a warm-woollen coat from a store. A physicist conceives a warm-woollen coat as a *thermal insulator* that isolates human body from external cold. In scientific terms, the warm-woollen coat does not heat up the human body (everyday social languages), instead, it does isolate it from a colder environment. A physicist therefore cannot buy a coat from a store by using a jargon like thermal insulator. As an inference, everyday social languages of individuals are also vital to communicate healthfully in a specific stratum of the society (Mortimer, 1995; Tulviste, 1991). Thus, there is no an immediate need of terminating individuals' everyday social languages that are *sine qua non* for engaging in the society.

Educational Implications

As proved in the current study, teaching and learning science can be considerably sophisticated in the context of Vygotskian perspective favouring a model of cognitive development from social to individual (Leach & Scott, 1995). Science teachers should hold a considerably specific *pedagogic noticing* (e.g., Jacobs, Lamb, & Philipp, 2010; van Es & Sherin, 2002; 2008) in planning, designing and implementing the model of teaching sequence proposed in the present study. First of all, learning demand should be detailed for different science subjects and in-class teaching activity should be planned according to the amount of the determined learning demand. However, science curricula are not prepared by taking learning demand phenomenon into account. Thus, science teachers should enhance specific ways of pondering on science curriculums to delve them into by taking learning demand. When it is the case, linear ways of using of a curriculum will not function to plan and design learner-centred activities.

To support, in the same science subject, there can be higher or lower learning demands requiring different modes of teaching. In a sense, science teachers should *re-organise* science curriculums by making categorisations of science subjects incorporating higher or lower learning demands. This also means that science teachers have to develop and use a distinctive *pedagogical lens* to classify curricular outcomes according to their presumable learning demands. It is therefore considerably needed that science teachers have to continuously juxtapose, compare and contrast the emergencies of the two differently-oriented social languages (everyday vs. school science) within science curriculums to make wise projections regarding how- and what-aspects of teaching planning. For instance, science teachers should be

dramatically aware and knowledgeable pertaining probable student-led alternative conceptions by checking related studies.

Moreover, as shown in the current study, science teachers must have a two-fold accountability to undertake an authentic learner-centred teaching sequence or activity. Prioritising student-led everyday social languages, launching and maintaining a teaching sequence by focusing on the student-led externalisations are dramatically important for an effective and yielding science teaching process. However, as exemplified in the present study, science teachers have to hold further accountabilities: accountability to the learning community; accountability to accepted standards of reasoning; and accountability to knowledge (e.g., Michaels & O'Connor, 2002; Michaels, O'Connor, & Resnick, 2008). Thus, when science teachers plan and design teaching sequences based on the model proposed in the current study, they should assume that they will be inviting their students to a *discursive journey* from a social language to another.

For a final comment, it should be asserted that above-mentioned rather complex reasoning about teaching science may not be developed or adopted by most of the science teachers (Cochran-Smith, 2005; 2006). It will not be fair to expect science teachers to use the proposed thinking tools immediately, effectively and routinely in their own classrooms. Thus, the proposed teaching planning model can be presented, discussed and re-considered by the practical contributions of science teachers within professional development programs. Therefore, proposed concepts, reasoning tools and the model of teaching should be considered as a core component of professional development programs devoted to the enhancement of the generic pedagogical content knowledge of science teachers in teaching school science effectively.

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