GoScience Enhancing Comprehension

METHODOLOGY

GoScience project: creativity and enhanced comprehension in science teaching and learning

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ABOUT THE METHODOLOGY

The methodology is the corner stone to build and implement a systematic approach for science teaching and learning focused on comprehension and on active student involvement in the educational process.

The methodology aims to provide teachers with knowledge, skills and tools to build their teaching around the concept of enhancing comprehension, which is the focal point of the project GoScience.

The methodology will show teachers how they can actively involve the students in the educational process and encourage their creativity. The methodology is built on the concept of adopting a student-centered approach of teaching.

With this methodology we want to help teachers work with students in a way which will allow the students to construct their knowledge actively, to activate their previous knowledge and to relate new structures to the existing ones.

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1. METHODOLOGICAL FRAMEWORK FOR ENHANCING COMPREHENSION IN SCIENCE EDUCATION IN HIGH SCHOOLS

Lack of comprehension is the main problem of underachievement in schools, especially when it comes to science subjects. And this leads to many problems both for students and teachers. For students it hinders their ability to use the knowledge in everyday life, decreases their functional literacy and as a result it limits their abilities to work on their transversal competences, since they are mainly a passive side in the education process and the development of transversal competences requires for students to be active and make decisions and take responsibility for how they are going to exist in the world after graduating school. For teachers lack of comprehension lowers their motivation to work and introduce new pedagogical tools and instruments.

1.1. Need of coherence of the educational content with the comprehension model of students

The ability to comprehend is probably one of the most important abilities of people. Comprehension can be worked on, developed, improved as any other ability we have. It is not only important but crucial for the education process, since it is responsible for the most difficult task - to pass on particular agreements, different notions, processes and concepts not as a formal text, but in a manner that these notions and concepts find their place among other concepts already existing in the students' knowledge database, relate to them and most of all be understood in a way, which will allow them to be further applied in everyday life. Comprehension gives us access to know about the world around us. Our way to be and to behave is deeply influenced by our perception and how we comprehend the information that surrounds us.

Science is a discipline that relies heavily on students' ability to understand new terms and concepts. Additionally students may have trouble understanding how science information is displayed and organized (such as in figures, diagrams, graphs, and drawings); grapple with technical or specialized vocabulary to convey scientific ideas and concepts; and have difficulty understanding the syntactic structures used to express complex scientific processes and concepts.

The problem is that no matter how close teachers try to be to the conscious, cognitive and thinking models of kids they usually fail for the fact that the neurological connections in their brains, their experience and knowledge, are very different from these of the kids. Introducing new scientific language to students can cause considerable confusion, particularly when the students may have established a different understanding of the terms from their everyday use. Careful thought needs to be given to the selection of new scientific terms, the choice of language used in definitions and the implications of prior understandings based on everyday use.[1]

With the current methodology, developed under the GoScience project students will be helped to construct their knowledge actively, to activate their previous knowledge and to relate new structures to the existing ones. Teachers need to influence the students' processes of problem understanding by structuring the objective task environment as clearly as possible. Teachers must recognize the individual thinking and acting of the students and assess whether they are using their existing knowledge meaningfully. Communication between teachers and students is mainly verbal. And unlike in private talks discussions at schools are carried out in scientific language. Researches in science education in Europe show that comprehension in the communication between teachers and students is a major problem. And it should be addressed directly as the reason for

[1]https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/science/continuum/Pages/scilang.aspx

underachievement despite any additional factors as lack of motivation in students, obsolete teaching practices, lack of lab equipment, etc.

Science education in Europe usually begins with one general integrated subject in primary education. In secondary education science teaching is usually split into subjects. However the links between the different subjects are rarely emphasized. Not only that but in science curricula in schools it is often that different scientific concepts are distributed among grades in school in unclear manner, which makes both teaching and learning difficult. And this is a serious problem for comprehension too. The current methodology and the GoScience project outputs in general are planned to include pedagogical tools namely to relate different concepts between science subjects in school, thus providing the "big picture" to students, who will be able to make connections and learn system thinking, instead of focusing on memorizing unclear concepts.

1.2. Defining comprehension

If we investigate the Latin root of the word comprehension we will see it means "taking together".

What is that, which is taken together – it is about all the ideas, meanings, concepts a person is surrounded with, in order to make sense of the world a person exists in.

There are different definitions of comprehension given through the years from different researchers. In early studies comprehension was strictly related to prior knowledge: We know that people with high amounts of prior topic knowledge comprehend text better than those with lesser amounts (see Anderson & Pearson, 1984). We also know that people who know more word meanings comprehend text better than those who know fewer (see Graves, 1986, for review). Anderson and Pearson (1984) suggested three ways in which prior knowledge may affect comprehension. Prior knowledge may:

- enable students to make inferences about their reading,

- direct their attention to information important in a knowledge domain,

  and/or

- provide a plan for recall.

These are not mutually exclusive. Indeed, prior knowledge affects comprehension in all of these ways.

Definitions are also related to the means and type of information a person perceives like:

"Comprehension is the process of simultaneously extracting and constructing meaning through interaction and involvement with written language" (about reading comprehension, Rand Corporation, Reading Study Group, 2002)[2].

"Comprehension is the act or fact of grasping the meaning, nature, or importance of particular object or information".[3] (about understanding by a research subject of information disclosed orally or in writing).

Also it is about how successful we are in interacting with others: "Comprehension is the ability to find, evaluate, compare, manage the received information and pass it to others" (Weber and Johnson, 2000).

It is important to point out that the process of comprehension is not a sole process. It is related to all the neuropsychological processes active in a human's brain for the recognition, processing and use of the information we receive in a specific context we are put in. Actually comprehension is closely related to memory. Comprehension and memory have a long history of study in psychology and are impossible to separate from one another. In fact, memory may be seen as an inevitable, albeit imperfect, by-product of normal comprehension (Craik & Lockhart, 1972). How we comprehend something has implications for how it is remembered, and

[2] https://edu.glogster.com/glog/defining-comprehension-strategies-and-instruction-strategies/28xipnvreb6?=glogpedia-source

[3] American Heritage Dictionary, 4th ed

what is remembered is in large part a function of what was initially understood.[4]

Memory is one of the most important cognitive processes. If learning has to progress, remembering of what is already learnt is indispensable, otherwise every time the learner has to start from the beginning.

We have a notion that memory is a single process, but an analysis of it reveals involvement of different activities:

Learning: This is the first stage of memory. Learning may be by any of the methods like imitation, verbal, motor, conceptual, trial and error, insight, etc. Hence, whatever may be the type of learning; we must pay our attention to retain what is learnt. A good learning is necessary for better retention.

Retention: Retention is the process of retaining in mind what is learnt or experienced in the past. The learnt material must be retained in order to make progress in our learning. Psychologists are of the opinion that the learnt material will be retained in the brain in the form of neural traces called 'memory traces', or 'engrams', or 'neurograms'. When good learning takes place – clear engrams are formed, so that they remain for long time and can be remembered by activation of these traces whenever necessary.

Remembering: It is the process of bringing back the stored or retained information to the conscious level. This may be understood by activities such as recalling, recognising, relearning and reconstruction.

Recalling: Recalling is the process of reproducing the past experiences that are not present. For example, recalling answers in the examination hall.

Recognising: It is to recognise a person seen earlier, or the original items seen earlier, from among the items of the same class or category which they are mixed-up.

[4] Richard Jackson Harris, Elizabeth Tait Cady, and Tuan Quoc Tran, Comprehension and Memory, Kansas State University, 2002

Relearning: Relearning is also known as saving method. Because we measure retention in terms of saving in the number of repetition or the time required to relearn the assignment. The difference between the amount of time or trials required for original learning and the one required for relearning indicates the amount of retention.

Reconstruction: Reconstruction is otherwise called rearrangement. Here the material to learn will be presented in a particular order and then the items will be jumbled up or shuffled thoroughly and presented to the individual to rearrange them in the original order in which it was presented.

The memory is defined as 'the power to store experiences and to bring them into the field of consciousness sometime after the experience has occurred'.[5] Our mind has the power of conserving experiences and mentally receiving them whenever such an activity helps the onward progress of the life cycle. The conserved experience has a unity, an organization of its own and it colors our present experience.

During the comprehension process, memory comes into play as incoming perceptual inputs are connected to past knowledge or experience to construct an understanding of the incoming information. This constructed memory representation then can be used as a reference for interpreting future experience. This continuing interaction of comprehension and memory impacts many experiences, including memory for events, remembering whether something we know came from a book or real life, and constructing worldviews based on the input.[6]

Comprehension includes the following basic phases:

- Encoding of information
- Transfer
- Imprinting

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[5] Aman Sharma, Essay on Memory: (Meaning and Types), http://www.psychologydiscussion.net/essays/essay-on-memory-meaning-and-types/598

[6] There again

- Storage
- Retrieval
- Consolidation

It is all about activation of background knowledge and construction of cognitive representations (Situation Models). Activation of prior knowledge is effected of the domain-specific prior knowledge. Readers and listeners construct … simulations by reactivating and integrating traces of previous experience distributed across multiple perceptual and motor modalities in the brain. [7]

Ability to construct cognitive representations emerges early in life:

4-year olds are able to form "spatial perspectives of characters and their actions[8]

Children 7-13 years construct situational models faster during text reading than when listening[9]

Comprehension is also related to the emotional evolution of information. Memory involves remembering and forgetting. Remembering the pleasant experiences makes living happy, and on the other hand remembering unpleasant experiences makes living unhappy and miserable. So here forgetting helps individual to forget unwanted and unpleasant experiences and memories and keeps him happy. In this way, remembering the pleasant and forgetting the unpleasant both are essential for normal living. In the case of learners, remembering is very important, because without memory there would be no learning. When we refer this to the education process in general, and science education in particular, it is very important to create the environment of "happy" learning for students – also because science subjects are very often related to something difficult, unpleasant and unnecessary in students' minds – which makes the process of remembering and comprehending very difficult.

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[7] Ahmed M. Abdelal, Ph.D. Neurobiology of Listening & Reading Comprehension, & Brain-Based Strategies for Maximizing Performance, Bridgewater State University, ASHA 2014

[8] Ziegler, Mitchell, & Curie, 2005; Rall & Harris, 2000

[9] Engelen, Bouwmeester, Bruin, & Zwaan, 2011

Emotions regulate the learning process by:

- Guiding our thinking process;
- Helping connect new information to existing information;
- Providing us with motivation;
- Providing a meaningful context;
- Enabling people to live the experience.

Based on the above the definition for comprehension with which we work in the GoScience project is the following:

"Comprehension is the process of simultaneously extracting and constructing meaning through interaction with visual/oral and/or written information evaluating and processing it in such a way that allows the person to pass this information to others."

1.3. Types of comprehension

In the methodology two main types of comprehension are considered - reading and listening comprehension, because in the science education in schools these are the most common methods and materials used for teaching - using textbooks and/or listening to the explanations of the teachers related to scientific texts, experiments, graphs, etc.

1.3.1. Reading comprehension

Reading involves cognitive processes which enable readers to comprehend the meaning of a text by decoding printed symbols. These multiple cognitive processes are not active at all times. There are two types of mental processes lower-level and higher-level processes, which are used depending on the type of the reading activity. Lower-level processes focused at the word level are skills which should become automatized during early education and are carried out unconsciously whereas higher-level processes based on the overall interpretation of the text are developed throughout the reader's life.

Reading comprehension is "intentional thinking during which meaning is constructed through interactions between text and reader. . . . The content of meaning is influenced by the text and by the reader's prior knowledge and experience that are brought to bear on it" (Reutzel & Cooter, 2011). The RAND Reading Study Group (2002) noted that reading comprehension involves four components:

- the reader
- the text
- the activity (e.g., discovering the author's main idea, understanding a sequence of events, thinking about a character's intent in a story, etc.)
- the situational context or the actual setting where reading occurs (individual reading or a social activity in which people read the text together)

According to Pressley (2005) the development of reading comprehension is a two-stage process:

- the first stage (the construction phase) begins with "lower processes" focused at the word level: word recognition (phonics, sight words), fluency (rate, accuracy, and expression), and vocabulary (word meanings).
- the second stage (the integration phase) involves higher-level processes and focuses on the overall interpretation of the text (relating prior knowledge to text content and consciously learning, selecting, and controlling the use of several cognitive strategies for remembering and learning from text). During the second phase of processing meaning, ideas from the text are connected with what we already know, our prior knowledge, and new concepts that do not fit with the meaning of the text are deleted from our network knowledge.

Another concept we should consider when analyzing reading comprehension is the schema theory.

When reading people use prior knowledge to comprehend and learn from text. All our knowledge is organized and stored into acquired knowledge structures (schemas/schemata) like folders in a computer. Such schemas (or schemata) are used like a **mental framework/network** to represent and **organize information**. The importance of schema theory to reading comprehension also lies in how the reader uses schemata.

Schemata enable us to **recall,** organize memory, focus attention, interpret experience, or try to **predict most likely outcomes of events**. A text provides directions for readers as to how they should retrieve or construct meaning from their own previously acquired knowledge. According to schema theory, comprehending a text is an interactive process between the reader's background knowledge and the text. Efficient comprehension requires the ability to connect the text (reading passage) to one's own knowledge. In the educational process **teachers' task** would be to **help students to develop new schemata** and **establish connections between them**.

1.3.2. Listening comprehension

Listening comprehension is only part of the whole system of cognitive recognition and understanding of information provided in specific context. When we speak about science education in schools and development of listening comprehension, we need to have in mind that currently scientific topics are explained through scientific language, which hampers the understanding of kids; their educational success in sciences is mainly related to the word skills of the teachers and their ability to explain. Researches involving a wide range of educators in a number of countries have consistently found that teachers do most of the talking in classrooms. Language plays a crucial role in the formation and development of concepts. This suggests that a teacher's language is vital in teaching science and creating the condition for meaningful learning.[10]

Listening comprehension encompasses the multiple processes involved in understanding and making sense of spoken language. These include

[10] https://www.weforum.org/agenda/2015/06/why-language-is-so-important-in-science-teaching/

recognizing speech sounds, understanding the meaning of individual words, and/or understanding the syntax of sentences in which they are presented.[11]

Listening comprehension is the ability to know the words, which one hears and relate to them in some way, based on his/her prior knowledge and experience. Good listening comprehension allows the listener to understand the information he is presented, remember it, discuss it, and even retell/present it in his own words.

Listening comprehension also refers to recognizing the rhythmic-melodic elements of the speech - the emphasis, the intonation, the length of the vocals, etc. and making relevant conclusions based on context, real-world knowledge, and speaker-specific attributes (e.g., to what information the speaker has access and about what he/she is likely to be talking). For longer stretches of language or discourse, listening comprehension also involves significant memory demands to keep track of causal relationships expressed within the discourse.[12]

Listening is the ability to fully understand a message which a speaking or a loudly reading person desire to give. Listening is an important part of communication and education process. According to Güneş (2007: 74), listening is not only done in order to set up communication, but at the same time it develops learning, understanding and mental skills. According to this, listening is not just the process of hearing sounds correctly. Listening is the whole of mental activities realized in order to understand what is heard. That is to say, listening means making choices from among what is heard, organizing them, integrating what is transferred by the speaker with background knowledge and structuring them mentally. Listening in educational communication includes carefully following and perceiving messages sent by the speaker to the listener and making sense of them by retrieving relevant experiences from the memory. Since most of the teaching is based on verbal explanation,

[11] Nadig A. (2013) Listening Comprehension. In: Volkmar F.R. (eds) Encyclopedia of Autism Spectrum Disorders. Springer, New York, NY
[12] There again.

being competent at listening on its own is a communication skill for both the teacher and the student (Başaran, 2005: 433).

1.4. Levels of comprehension and levels of creativity

Why connect levels of comprehension and levels of creativity? The GoScience project aims at enhancing comprehension in science education not only by providing teachers with new skills and knowledge for pedagogical approaches and instruments focused on comprehension, but also by fostering students' creativity. If teachers know how to work on fostering students' creativity it will also help them improve their comprehension on the scientific subject – points 2 and 3 in the methodology speak about that more in detail. Also connecting levels of comprehension and levels of creativity can help teachers measure both, since they are interrelated: a higher level of creativity shows higher level of comprehension and vice versa; linking levels of comprehension and creativity can also help teachers understand more about the prior knowledge the students have access to and also about the cultural background and context of this knowledge.

1.4.1. Levels of comprehension in reading

When we read, whether it is a story or information, we learn to think. We make meaning and comprehend in three ways (three levels of reading comprehension):

Readers make meaning through **literal comprehension**. We demonstrate understanding of what we have read by retelling and summarizing in our own words what has been made explicit – the facts.

Readers make meaning through **inferential comprehension**. We demonstrate understanding of what we have read by making inferences, interpretations, and reflections about what is implicit in the text. We do this supported by evidence from the text or by making connections to background knowledge and personal experience.

Readers make meaning through **analytical comprehension**; we see through the eyes of a writer, analyzing and evaluating the quality of the writing. We demonstrate understanding by identifying traits of good writing. In doing so, we improve our ability to write.[13]

1.4.2. Levels of comprehension in listening

Understanding how to teach listening necessitates understanding of the different types of listening that you want students to develop. Each level has corresponding skills.

Discriminative listening is foundational to the other levels. Discriminative listening is being able to listen to pertinent sounds as well as being able to distinguish between verbal and nonverbal cues. Having students attend and interpret the speaker's mannerisms (e.g., smiles, crossed arms, clenched fists) is a way to teach how nonverbal cues convey the speaker's message.

For example, being adept with discriminative listening puts students in a better position to listen for specific details (i.e., precise listening), use vocal expressions and nonverbal cues to make decisions about the speaker's message (i.e., strategic listening), use nonverbal cues to determine a speaker's perspective (critical listening), and use sounds to appreciate what they are listening to (i.e., appreciative listening). These are ways that foundational discriminative listening skills come into play in other listening levels. That said, one level is not necessarily a prerequisite to the next. Students can be adept with one type of listening, yet not with another and they can develop listening skills at all levels simultaneously.

Precise listening helps ascertain specific information. Teaching children how to recall details, how to paraphrase information, how to follow spoken directions are the types of skills that call for precise listening.

Strategic listening is basically helping students listen for understanding. Teaching students how to connect the ideas they are hearing with their prior knowledge about the topic, how to summarize information, how to

[13] https://www.linkedin.com/pulse/three-types-comprehension-make-simple-clear-brian-kissman

compare and contrast information, and how to make inferences are skills associated with strategic listening. This level calls on listeners to concentrate on the intended meaning.

Critical listening is all about helping learners not only comprehend the spoken message, but how to evaluate it. They are able to scrutinize and analyze the message, looking for logic and statements that either support or negate the stated message, in order to be convinced that the speaker is credible. Teaching students how to recognize bias, distinguish among fact and opinion, and detecting propaganda techniques are skills that enable them to listen critically.

Appreciative listening is appreciating the overall style of the speaker and is fairly individualistic. As we listen at this level, different aspects of what we are hearing catch our attention. This is why some might enjoy listening to some types of poetry, songs, musical scores more so than others. Teaching students how to recognize the power of language, appreciate oral interpretations, and understand the power of imagination are ways to help learners become appreciative listeners.

In summary, there are five listening levels and each has associated skills. These are shown in the table below. Teaching listening skills to students is about showing them how to listen rather than telling them to listen.[14]

1.4.3. Levels of creativity

Great innovators from Archimedes in his bathtub to Einstein riding his elevator of relativity have used analogies to creatively solve complex problems. We use analogies to transfer information that we believe we understand in one domain, the source, to help resolve a challenge in an unfamiliar area, the target.

Analogical Creativity is the first type of creativity recognized. For example, the design of vacuum cleaners was largely unchanged for nearly a century when inventor James Dyson used a different analogy, cyclones, to devise a new way to separate particles through the spinning force of a

[14] Michael F. Opitz, Teaching levels of listening, 2017, http://blog.listenwise.com/2017/03/teaching-levels-listening/

centrifuge. Despite the differences between similarities, metaphors, and analogies, these are all functions of analogical thinking. In essence, analogies are bridges that allow our cognitive processes to quickly transport clusters of information from the unknown to the known, and back again. Analogies can be both rational and emotional. For example, "Happiness is a warm puppy." It is not uncommon to see analogical creativity at work in commercials where we are assured that drinking this beverage is like jumping into a cool pool on a hot summer afternoon or that tasting this new gourmet chocolate is similar to a first kiss. Feeling refreshed and loved we consume the calories and put on the pounds because we relate to the analogy.

In GoScience project we count a lot to the analogical creativity of children to help them understand the scientific concepts in a better way (see point 2, 2.1. and 2.2. – use of analogies, metaphors and models as approach in scientific education)

One of the challenges of analogical creativity is that the source of the analogy is often technically and culturally specific. Consider a group of computer hardware developers being asked "How is creating a new microprocessor like a NASCAR race?" While presumably they all know how an integrated circuit operates they may have never been to a stock car race or may have a negative impression of them. So it is imperative that you use analogies that can be deeply understood across the wide range of expertise and cultures when working in a diverse group. Swiss psychologist Carl Jung suggested that there archetypes, universally understood prototypes, of symbolic events that can used across cultures because they represent common experiences - sunrise, birth and harvest to name a few. These archetypal events can be used to overcome cultural differences when using analogical creativity.[15]

Narratological Creativity: Have you ever heard a child try to get its story straight? Or maybe you have dear friend who always blows the punch line of a good joke. Both are examples of how hard to tell a coherent, meaningful and compelling tale. Stories are a complex mash up of

[15] https://www.huffingtonpost.com/jeff-degraff/mastering-the-five-levels_2_b_4848308.html

characters, actions, plots, description, grammar and sequence. Most importantly, they have a narrative voice - our voice - authentic or personified. How we tell the tale can either energize the most mundane anecdote or dampened even the most rousing spellbinder. The philosopher Plato understood the persuasive power of the storyteller and was so concerned that he banished them from his Republic and urged Athenians to restrict the teaching of rhetoric because it covers up an individual's lack of knowledge. What would he think of political ads or commercials for beauty products?

Narrative is a story communicated in sequence. It is *how* the tale is told. Stories can be readily deconstructed and reconstructed to make different versions or new concoctions altogether.[16]

Fostering narrative creativity is part of GoScience approach of enhancing comprehension (you can see more about it in point 2, point 2.3 and also 2.4)

Intuitive Creativity: This final and most challenging level of creativity has often been promoted to the realm of spiritual and wisdom traditions. This is where creativity becomes bigger and possibly beyond us - it transcends our individuality. When we speak of intuition, dreams or signs it suggests that we may be receiving ideas as much as we are generating them. Where creative ideas come from may determine their importance and whether we should pursue them or not. For example, if you have a dream about going home that you interpret as simply the residue of the day it may have little significance for you. But, what if you thought that same dream was delivered to you by an angel and that it was a premonition to keep you safe? We all have moments of insight that seem to spring from someplace just beyond the limits of our rational thinking. These can be deep wells of flowing creativity or a bottomless abyss of superstition and delusion.[17]

[16] https://www.huffingtonpost.com/jeff-degraff/mastering-the-five-levels_3_b_4890363.html
[17] https://www.huffingtonpost.com/jeff-degraff/mastering-the-five-levels_b_4934652.html

2. APPROACHES FOR ENHANCING COMPREHENSION

The methodology considers several approaches for enhancing comprehension, which based on needs analysis taken, research, and pilot testing in the field of science education in schools have proven their efficiency and adaptability to different educational contexts, curricula and socio-economic background of the educational systems around the world.

2.1. Use of analogies and metaphors

An analogy is a similarity between concepts. Analogies can help students build conceptual bridges between what is familiar and what is new. Often, new concepts represent complex, hard-to-visualize systems with interacting parts (e.g. a cell, an ecosystem, photosynthesis).

Analogies can serve as early "mental models" that students can use to form limited but meaningful understandings of complex concepts. Analogies can play an important role in helping students construct their own knowledge, a process that is encouraged in the Standards and consistent with a constructivist view of learning. As students' develop cognitively and learn more science, they will evolve beyond these simple analogies, adopting more sophisticated and powerful mental models.
When students study new concepts, meaningful learning proceeds when they find and visualise connections between a newly taught context and what they already know. This is especially important in inquiry learning where connections are built between familiar and non-intuitive science

contexts.If the analogies are appropriate, they promote concept learning because they encourage students to build links between past familiar knowledge and experiences and new contexts and problems.
An analogy is a comparison of the similarities of two concepts. The familiar concept is called the analogue concept and the unfamiliar one the target concept. Both the analogue and the target have features (also called attributes). If the analogue and the target share similar features, an analogy can be drawn between them. A systematic comparison, verbally or visually, between the features of the analogue and target is called a mapping. A conceptual representation of an analogy, with its constituent parts, appears in Figure 1.

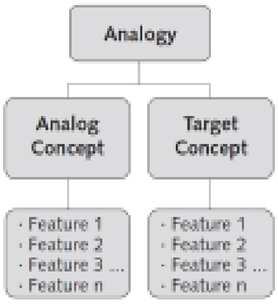


Figure 1. A conceptual representation of an analogy, with its constituent parts.

Both analogies and metaphors express comparisons and highlight similarities, but they do this in different ways. An analogy explicitly compares the structures of two domains; it indicates identity of parts of structures. A metaphor compares implicitly, highlighting features or relational qualities that do not coincide in two domains.
Despite the allegations against figurative language, metaphor is helpful, at times essential, in performing three functions: establishing terminologies, expressing abstract concepts, and developing hypotheses. Analogies and metaphors may make new information more concrete and easier to imagine.

2.2. Use of models

The word "model" denotes the interpretation of concepts or relations used in a theory, rule, instruction, or another notion by expressing them by/through well-known, familiar phenomena and natural, conventional

relation that creates a conception that is easy to perceive intuitively—image. It may be a drawing, an animation, a scheme and so on. It should be emphasized that models are made by the students, but the teacher act as an organizer and guide of the process of making models.
The models require an equalization of complicated science systems to a certain process or phenomenon one can observe in everyday life. With models it becomes possible for a student to build an interrelation between his previously gained knowledge about the world order and the complex information of science just by using the occurring associations. An association originated in this way and in the framework of the mentioned approach is called a comprehension model.

2.3. Use of illustration, explanation and colloquialism

Together with analogies illustration, explanation and colloquialism are strategies to convey scientific meaning to students in a way they can more easily understand it and relate it to the already existing knowledge they possess.

Illustration	Speaker gives several examples to illustrate a concept.
Explanation	Attempt by the speaker to define a scientific jargon word he/she uses.
Colloquialism	A simplification of a scientific concept in everyday language that does not have a precise scientific meaning.

Source: Hinko, K., Seneca, J., Finkelstein, N., Use of Scientific Language by University Physics Students Communicating to the Public

Illustration: Speaker clarifies a discipline-specific science word by giving one or several examples of familiar scenarios that can be compared in terms of scope or scale. Illustrative phrases differ from analogies in that they are direct comparisons and share the same properties of the original phrase – for instance, describing how cold something is by listing other cold objects. Examples include:

"By tiny I mean **much smaller than not even a human hair, but less than a thousandth of a human hair**, or even smaller."

"[...] if you were to take **ten Antarcticas, put them all together, and put them into your freezer, you wouldn't even be even close to this cold as we go**."

Explanation: Speaker attempts to provide a description of the characteristics or mechanisms of a discipline specific concept. The explanation is often given as a definition of the word or phrase. Explanations differ from analogies and illustrations in that they are not explicitly comparative. Examples include:

"A vacuum **is essentially a place that has no air**"

"I take molecules, **which are just** small (...) groups of atoms put together"

Colloquialism: Speaker employs informal language to describe a discipline-specific science phrase in place of more precise terminology. Verbs or adjectives that are familiar to the audience are used instead. Examples are:

" [...] that's really just a big word for saying we **shoot lasers** at things and see what happens."

"[...] those atoms are going to **wiggle around** inside that material."

2.4. Use of art and drama

Combining the arts and drama standard curricula together can create a richer and more lasting learning experience for students who believe that learning science is boring in classes. Drama and arts on their own are an educational area developing and training a child and at the same times an effective method developing creativity. The use of arts and drama in class is a great strategy to work on students comprehension skills. The main goal of implementing arts in science education is to give students the opportunity to express their thoughts and feelings in the context of their different cultures and background also to understand science through the lens of their creative activity in arts. Arts and drama require the active participation of the students and thus help them to transform the conceptual information offered by the science lesson to personal experience and thus remember it more easily. Examples of art and drama activities and how to be implemented in class are given in point 3 below.

2.5. Use of science concept maps

A concept map is a graphical representation of the relationship among terms. Although there are many variations in the way you can design concept map activities, open-ended activities that allow students to construct their own map structure are the most revealing.

As students are introduced to new science concepts, they embark on a cognitive process of constructing meaning and making sense by consciously or subconsciously integrating these new ideas with their existing knowledge. Concept maps provide a unique graphical view of how students organize, connect, and synthesize information. As a result, concept mapping offers benefits to both students and teachers. Concept maps give students an opportunity to:

- think about the connections between the science terms being learned
- organize their thoughts and visualize the relationships between key concepts in a systematic way
- reflect on their understanding.

In sum, concept maps allow students to think deeply about science by helping them to better understand and organize what they learn, and to store and retrieve information more efficiently. Students also articulate and challenge their thoughts about science when they discuss their maps with each other.[18]

Concept maps are typically hierarchical, with the subordinate concepts stemming from the main concept or idea. This type of graphic organizer

[18] Jim Vanides, Yue Yin, Miki Tomita and Maria Araceli Ruiz-Primo, Using concept-maps in the science classroom, https://web.stanford.edu/dept/SUSE/SEAL/Reports_Papers/Vanides_CM.pdf

however, always allows change and new concepts to be added. Usually concept maps are defined into two main groups:

- hierarchical – represent information in descending order of importance
- non-hierarchical – represent information in cluster or network pattern.

3. PEDAGOGICAL TOOLS AND RESOURCES FOR ENHANCING COMPREHENSION

This part of the methodology is developed to give science teachers examples and practical tools to use in class as well as skills and knowledge to develop pedagogical tools themselves for teaching science in class.

3.1. Building effective analogies

Example 1: What We're Made Of (biology)

Students saw a Superman movie and were arguing about whether the Man of Steel was really made of steel. The students quickly agreed that Superman wasn't made of steel, but that got them thinking about what real people are made of.

Before the students will actually have a formal lesson on the cell, the teacher can use Lego bricks to make an analogy. Asking questions like: "What are these little bricks and what can you do with them?" Finally, we can conclude Lego bricks get put together to make bigger things. Likewise, cells get put together to make bigger things—things like people, dogs, cats, oak trees, or rose bushes—these living things are made up of cells—lots and lots of tiny cells. So we can use this example to explain it, this is an analogy between Lego bricks and cells. Making an analogy helps the students to understand something new by comparing it to something you already understand.

So, by using the approach of teaching with analogies the teacher:

- Introduces the target concept, the cell, to students.
- Reminds students of what they know of the analogue concept, a Lego.
- Identifies relevant features of the cell and a Lego.
- Connects (maps out) the similar features of the cell and a Lego.
- Indicates where the analogy between the cell and a Lego breaks down.
- Draw conclusions about the cell.

Moreover, we can continue with the explanation showing cell diagrams, photos, and videos and describing the different kinds of cells. The students learn that the cells in their bones are different from the cells in their heart or brain and that their bodies are made up of about 200 different types of cells, all working together. As they progress through a unit on cell structure and function, students eventually learn that each cell must make the molecules it needs to survive, grow, and multiply—and that each cell is made up of parts, including organelles, with important functions.

As the students learn about the parts of cells and the function of these parts, we can propose other analogy-based activities such as making an "edible cell" from gelatine, fruits, and candies.

We can rely on the teaching with analogies approach, following its steps:

- Introduce the target concept, the animal cell and its parts, to students.
- Remind students of what they know of the analogue concept, the gelatine mould and its parts.
- Identify relevant features of the cell and the gelatine mould.
- Connect (map) the similar features of the cell and the gelatine mould: e.g., nucleus (plum), mitochondria (raisins), lysosomes (M&M candies), endoplasmic reticulum (gummy worms), ribosomes (candy sprinkles), Golgi complex (folded hard candy ribbon), cytoplasm (gelatine), and cell membrane (gelatine surface).
- Indicate where the analogy between the cell and the gelatine mould breaks down (e.g., the cell is alive and tiny, with parts that only superficially resemble the fruits and candies in the gelatine mould).
- Draw conclusions about the cell (e.g., cells are the building blocks of organisms and all the functions that sustain life occur within a single cell).

Example 2: Chemistry cooking analogy (chemistry)

We will focus on the use of chemistry cooking analogy with the purpose of contextualizing the teaching of chemistry, when designing a better teaching-learning, achieve quality education and increase interest students towards studying science.

To make an educational intervention proposal translatable to the classroom, it will need to develop content and achieve the objectives and powers specified in the laws for the course and defined subject.

Therefore it is proposed for implementation in the second course of secondary school, focusing on content and key competencies to be developed, such as research and experimentation.

The following activity is proposed to work on the contents of general properties of matter, mass and volume. Mass and volume measurements will be made, directly and indirectly, of solid and liquid foods within the framework of a cooking recipe, while preparing a sponge cake.

The students will be grouped in groups of 3 or 4 to make a cake per group. Before starting to make the cake, they will be asked to observe the packaging of the different ingredients, observing in which units the quantities they contain are expressed, if there are differences between solid and liquid foods.

It is necessary that they become familiar and learn to use conversion factors appropriately, since they will use them throughout secondary education and university if that is the case. This subject is difficult to assimilate for the students, who refuse to use them, and do not understand its usefulness or some of the equivalences. Therefore, it is intended with this experience to introduce them in a more graphic and deductive way. Although the amount of liquid products is usually expressed in L or mL, in the recipe that the students will follow, these will be expressed in dm^3. As both the volumetric laboratory and the volumetric material to determine volumes are calibrated in L or mL, they will be asked to build a dm^3 with carton containers to check their capacity before beginning the recipe. From there, they can make the necessary equivalences between dm^3 and L or mL and make the necessary measurements with the available material.

Following the steps of a recipe, they will weigh and measure the indicated quantities of the different ingredients using a scale (laboratory and kitchen) and volumetric laboratory or even kitchen equipment (measuring cups). They will be guided to deduce whether masses of different solid ingredients have the same volume, and whether equal volumes of different liquid ingredients have the same mass. To also perform some indirect measurement of the volume of a solid, by immersion in a liquid, students will check by this method if the volume indicated in a packet of butter, for example, corresponds to that determined by this method, and perform the calculation of its volume based on its measurements, which will convert to dm3 to see this relationship more graphically.

In this example of the teaching with analogies approach, the steps are:

- The teacher introduces the topic, which they will have previously studied in class: the concepts of mass and volume and the methods to determine the mass and volume of solids and liquids.
- Next, the teacher will present the analogous foods, whose quantities (masses and volumes) should be measured to prepare a sponge cake. Before starting, they will be urged to look in the packaging of the different ingredients, in which units the quantities they contain are expressed and to point out differences between solid and liquid foods.

- The teacher will also give the recipe for the cake. Students should check if they have all the necessary ingredients and all the instruments, laboratory or kitchen. At this point, students will notice that, in the recipe, the necessary amounts of liquid ingredients are expressed in dm3. The teacher will then provide them with carton containers and will instruct them to build a dm3 with them (cube 10 cm on each side) to check their capacity. With this equivalence, they will be able to carry out the necessary conversions between dm3 and L or mL in order to measure the liquid ingredients with the available material.
- The teacher will emphasize the relationships between the measurements that are made during the preparation of the cake and laboratory techniques, and between the kitchen and laboratory instruments suitable to perform them. As mentioned, with the intention of also making some indirect measurement of the volume of a solid, by immersion in a liquid, students will be asked to check by this method the volume indicated in a packet of butter.
- The teacher will ask questions to the students to know their impression about the activity, if it has been easier to understand the topic, if they have assimilated well the concepts worked and if there is any doubt.
- Finally, students should draw conclusions about the topic and its relationship with everyday life. To complete this sequence, a 55-minute session is planned.
-

Example 3 "Expansion of the universe after the big bang" (physics): using pictorial verbal analogies[19]

"Expansion of the universe after the big bang can be compared to the inflation of a balloon"

[19] https://www.eduhk.hk/apfslt/v13_issue1/yener/page5.htm

Example 4 Using analogies in mathematics

In order to explain to students more easily to understand how to do subtraction and addition of negative numbers a teacher may use the following analogy: "Lets say you've got money. If you lost 88 cents and then you lost 5 cents more, whould you add or subtract to find out the total amount you lost?" (Math schema: "When you have a negative number minus another number, do you add or subtract")[20]

3.2. Model developing

With the use of comprehension models an equalization of complicated science systems to a certain process or phenomenon the person can observe in everyday life forms the bottom of the mentioned approach. It becomes possible for a student to build an interrelation between his previously gained knowledge about the world order and the complex information of science just by using the occurring associations. It should be emphasized that models are made by the students, but the teacher act as an organizer and guide of the process of making models.

Main features of the comprehension model can be formulated on the basis of the obtained experience, and they are as follows.

- The **theoretical accurateness** of the information included in the description of the model. For example, a student has created a comprehension model for the concept of "chemical equilibrium". It is a state of the system, in which the direct and reversed reactions are taking place with an equal rate. Consequently, two simultaneously occurring processes with equal rates and opposite directions should be represented in the student's chosen associative model. A student had chosen a picture as an associative model with a boat and two people rowing it, but each of them doing it in the opposite direction.
- **Simplicity**. A successful comprehension model will be such an associative image where a simple, self-evident process or phenomenon from the everyday life will be used for the origination of an association with the discussed scientific information. The key of the success requires that the process or event used in the model differs sharply from the science process which it tries to explain and is not connected with the last in any way.

[20] http://reasoninglab.psych.ucla.edu/KH%20pdfs/Richand_etal.2004.pdf

- **Visual perceptibility**. The model has to be visually attractive; however it should not be oversaturated with needless embellishments. The text should be short and concise.

The learning process using the models can be divided into the following stages:

Preparation stage → Creation of model → Improvement of model → Assessment of model

It should be understood that models will never accomplish creating for all the concepts of natural sciences and mathematics. Therefore the teacher has to assess carefully the learning content of the given subject and the suitability of the included concepts for creating associations with a daily processes or phenomenon in the preparation stage.

Table 1. Models made by students correctly

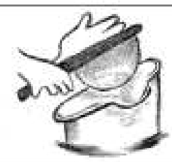
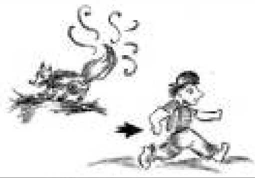
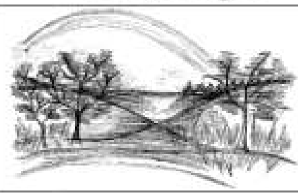
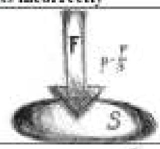
Model 1. ***Theoretical justification.*** Bodies are called absolutely transparent or diathermic if they let pass through themselves all the received energy. ***Description of the model.*** Heat radiation can be imagined as flour which is sifted through a sieve, and the sieve is the transparent body which lets the flour (radiation) through itself.	
Model 2. ***Theoretical justification.*** A diamagnetic is a substance which magnetizes in the opposite way to the direction of the applied magnetic field. The magnetization of diamagnetic materials usually is so weak that these substances are considered as non-magnetic in many cases. A magnet pushes off diamagnetic materials. ***Description of the model.*** The small animals – skunks have a method of self-defense. Skunks discharge a very unpleasant aroma when they are approached which scares away anyone who comes close to them. The skunk is an associative image of the magnet in this context but the possible enemy – the diamagnetic which is rejected.	
Model 3. ***Theoretical justification.*** A reflex is the response of a body to an irritation. ***Description of the model.*** The rainbow is the response of the Sun or sunny weather to the rain. In this case, the rain works as an irritant but the rainbow is the response.	

Table 2. Models made by students incorrectly

Model 1. ***Theoretical justification.*** Pressure is a perpendicular force which affects the unit of the surface area. ***Description of the model.*** The body is pushed against a certain surface with its own mass thus creating a pressure.	
Model 2. ***Theoretical justification.*** Sliding friction is created by one body sliding along the surface of another body. The force which delays the movement is called the force of sliding friction in this case. ***Description of the model.*** A box is sliding down from the hill. A friction force is arising that is delaying the movement of the box (decreasing its speed).	

Resource: "The Use of Associative Images (models) for the Development of Comprehension in Sciences Education", Aiva Gaidule, Uldis Heidingers, American Journal of Educational Research, 2015, Vol. 3, No. 10, 1305-1310

In order to work more easily with students it is helpful to clarify the difference between comprehension models and examples and experiments (see the table below):

	Model	**Experiment**	**Example**
Definition (explain what a model, experiment and example **IS**)	Model is intuitive acceptable situation where student can see that it is naturally and answer on question **„Why?"**.	Specially designed operations, equipment, etc., to observe any measurable or other observable modification of the parameters or to remain in the current state with changes to other parameters and answer on question **"How?"**	One representative of the things to be seen.
	ohm's law	**ohm's law**	**ohm's law**
Description (describe how a real model, experiment or example look like)	Take a full Coca Cola bottle, press the throat with your thumb and turn it upside down. Slightly open the hole with a thumb and spill a little cola, then open more and have more cola, but if the bottle was shaved, the cola escaped just as much as the open hole how not to shake the bottle to a more open hole.	Take the rust, voltmeter, ammeters, power source and lamp. We combine all this in the circuit and read the measurements at various settings.	Volume control on radio
Resources (describe what are the resources needed for a model, experiment and example to be developed)	Own brain + pen or/+ video or/+ any object + anything how to show the situation.	All what is used in science and engineering.	Recognition makes it possible to name another representative - an example.

3.3. Art games and installations

Here teachers can find number of resources that can be used to develop games in the science curriculum as well as guidelines and examples of how theatre and drama approaches can be used to enhance student's comprehension.

https://www.csun.edu/science/ref/games/ - the sourcebook for teaching science – offers ready templates for games in science subjects in English, which teachers can use in their classrooms;

https://www.legendsoflearning.com/teachers/ - Legends of Learning offers more than 1200 science games.

https://store.teachergaming.com/blog/5-great-educational-science-games-for-the-classroom-n7 - five examples of excellent educational games that bring on the science in the classroom!

https://www.bbc.com/bitesize/subjects/z2pfb9q - over 25 free scientific games on everything from food chains to solids, liquids and gases. Each topic has a game, a study guide, and a quiz to test what you have learned.

https://www.sciencemuseum.org.uk/games-and-apps - offers sixteen free online science games for students in elementary schools, the topics include energy, genetics, environmental science. Each game is accompanied by a set of links to support and complement the content that game addresses.

http://www.le-math.eu/assets/files/MATHeatre%20Guidelines%20-%20EN%20-%20Internet.pdf – guidelines how to implement theatre in math classes

Here are examples of some active exercises, using the drama approach that the science teacher can use:

- **Modeling**: have a student come up to the front of the class and instruct him/her to start a conversation with you on a topic. It might be helpful to give them a topic: What did you do in your previous science class? What is your favorite science concept and why? As they talk, model the difference between a distracted listener and an active listener (using the nonverbal and verbal cues). Afterwards, ask the student to compare what it was like to try to talk to someone who was distracted vs. someone who was actively listening?
- **Story Share**: This can be done as a large group discussion, or you can divide students into groups of four to make it more low-risk. Ask students to share a story about when they felt that they weren't being listened to. What was the situation? What was the outcome? What did it feel like to not be heard?

- **Variation**: Divide students into pairs. One person shares their story, the other listens. After one minute, stop the groups and ask a couple of listeners to paraphrase the speaker's story. How closely were they really listening?
- **Variation**: Do this as a group scene. Divide students into groups and have them create a scene in which a character wants to be heard and another character(s) will not listen. If students are having trouble coming up with a situation, suggest a parent/teen or teacher/student scenario.
- **Variation**: Ask a group of volunteers to do an improv scene. Pull one of the volunteers aside and instruct them to not listen to their fellow actors and to respond accordingly. Afterwards, discuss with the class about what it's like to try to act with someone who is not listening.

- **Learn about**: Students listen to each other in groups and then recall what they learned.

Divide students into groups of three. Each group decides who is A, B, & C. Have A start. He/She has 30 seconds to talk to B about his/her explanations about the scientific concepts he/she finds most interesting: animal groups, physics experiments he/she likes, chemical compounds used at home, etc. At the end of 30 seconds, B turns to C and tells C what he/she remembered about A's most interesting things. B then talks to C for 30 seconds about their favourite things. At the end of 30 seconds, C turns to A and tells A what they remember about B's favourite things. The cycle repeats with C talking to A, and then A telling B.

- **The end of the word**: Stand in a circle. Start with a word – "Cell."

The person beside you has to come up with a word starting with the last letter of the first word – "Laser." The next person does the same – "Reaction." Students have to listen and respond. Start slowly and gradually increase the speed. Set a timer (1 or 2 minutes) and see how many words you can get in that time. You can also start this exercise with smaller groups of 4 or 5 which is lower risk for beginning drama students.

- **Make a Story:** The goal is to make a seamless story among various players.

Have a group of 6 to 10 students line up in a row.Start by getting a suggestion from the audience. *("May I have the title of a story that's never been written…???")* After receiving the suggestion *(i.e. "The Best Science Class Ever")*, repeat it back – this is to ensure that the players have heard it. The Conductor points at one player who starts telling the story and keeps talking until The Conductor points at someone else. Have the next player pick up where the last improviser left off – have them do it as seamlessly as possible (even if it's mid-word or mid-sentence).Keep pointing at players and telling the story until you feel it is done.

3.4. Building science concept maps

In order to build an effective science concept map:

- **Start with a main idea, topic, or issue to focus on.**

A helpful way to determine the context of your concept map is to choose a focus question—something that needs to be solved or a conclusion that needs to be reached. Once a topic or question is decided on, that will help with the hierarchical structure of the concept map.

- **Then determine the key concepts**

Find the key concepts that connect and relate to your main idea and rank them; most general, inclusive concepts come first, then link to smaller, more specific concepts.

- **Finish by connecting concepts--creating linking phrases and words**

Once the basic links between the concepts are created, add cross-links, which connect concepts in different areas of the map, to further illustrate the relationships and strengthen student's understanding and knowledge on the topic.[21]

On the following link you can download example concept maps for scientific concepts, which can be used in the classroom: http://www.inspiration.com/inspiration-science-examples

[21] http://www.inspiration.com/visual-learning/concept-mapping

This is an additional resource for further reading of how concept maps can be used in science education: https://www.slideshare.net/biotechvictor1950/teaching-science-using-concept-maps

METHODOLOGY FOR ENHANCING COMPREHENSION IN SCIENCE EDUCATION IN HIGH SCHOOLS

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Additional notes:

Methodology to be used together with the developed materials for teacher training under the project, available at http://goscience.eu

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dennis-buchner-592120-unsplash

nadim-merrikh-307897-unsplash

sebas-ribas-310260-unsplash

Authorship:

Alise Betina, Riga State Technical School, Latvia
Anais Colibaba, EuroEd Foundation, Romania
Andrea Anzanello, Pixel Associazione, Italy
Andreea Ionel, EuroEd Foundation, Romania
Carmen Antonita, EuroEd Foundation, Romania
Dragos Zamosteanu, EuroEd Foundation, Romania
Elza Gheorghiu, EuroEd Foundation, Romania
Enric Gimenez Ribes, Associació L'Alqueria Projectes Educatius, Spain
Eng. Marieta Georgieva, Vocational High School "Prof. Dr. Assen Zlatarov, Vidin, Bulgaria
Dr. Miglena Molhova, Zinev Art Technologies, Bulgaria
Romans Vitkovskis, Uldis Heidingers, Latvian Education Foundation, Latvia
Ulla Theisling, Ulrich Diermann, Equalita, Germany
Undinė Diana Tumavičienė, Kauno Juozo Grušo meno gimnazija , Lithuania

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