Teacher's Guide

Science Bits

How to use Science Bits in the classroom

Best Practices

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INTRODUCTION: THE 5E INSTRUCTIONAL MODEL

The 5E Instructional Model is based on the theoretical foundations of constructivism, is widely supported by scientific research on how people learn, and has had a significant impact on the teaching of science over the last 30 years in the USA.

The teaching model that Science Bits adopts is called the 5E model because it consists of five phases whose names begin with the letter "E": *Engage, Explore, Explain, Elaborate, and Evaluate*.

The 5 phases of the 5E Model have been created to facilitate the process of **conceptual change,** that is, learning with an understanding of scientific concepts. Through this process, the ideas students bring to the classroom are reformulated as a result of new learning experiences.

The concept behind the model is to begin by elicitating the students' current knowledge, to make connections between this current knowledge and new knowledge through inquiry, to provide direct instruction of those concepts that students would not be able to discover on their own, and to provide students with opportunities to demonstrate their understanding through practice.

Developed by the Biological Science Curriculum Study (BSCS), the 5E Model has been used since the 1980s in many elementary, middle, and high schools in the United States. Studies of the 5E instructional model provide evidence of increased mastery of conceptual learning, improvements in skills development, and an increased interest in science.

Science Bits' 5E Model is an accurate adaptation of the original model by the BSCS. While real experimentation has a key role, the Science Bits version draws heavily on the use of multimedia resources. Additionally, it tries to meet and be coherent with the requirements set by official curricula with respect to the range of contents.

What is constructivism?

Constructivism, a learning theory widely supported by research in cognitive science on how people learn, assumes all individuals have prior knowledge, concepts, and ideas that act as a starting point from which to understand and integrate new knowledge. The constructivist model requires active learners who mobilize their prior knowledge and concepts to then compare and contrast them with new information. By employing and contrasting both sets of knowledge, learners build new models to understand reality.

Constructivism implies comprehensive learning through experience, allowing students to apply new knowledge in new contexts and learning situations. It avoids the mere memorization of scientific content imposed by the transmission model, which is often void of comprehension. It also acknowledges the importance of factual knowledge (facts with no implicit meaning) since conceptual knowledge (ideas with meaning) is built on these facts. However, constructivism does not involve learning based on merely acquiring scientific facts which are not organized within a conceptual framework that endows them with meaning.

Students' prior ideas and the problem of misconceptions

Constructivism believes that the process of learning new concepts is different from the process of acquiring factual knowledge, which occurs through transmission. The theory acknowledges that in order for students to integrate new conceptual knowledge (abstract ideas with meaning), they can't be seen as empty containers that need to be filled. Students bring their prior ideas to the classroom and make use of those ideas to understand the new ideas derived from new information and experiences.

Misconceptions are incorrect ideas that students have developed intuitively in order to make sense of the world around them from their everyday experiences, or even from classroom experiences. Although they are not correct from a scientific point of view, students use these ideas in their everyday lives and accept them as totally valid.

In school, these misconceptions must be replaced by correct scientific concepts, but it is not easy. Often times, students assimilate new ideas only to pass their exams and then go back to their previous ideas and keep using them in new situations. Several studies have demonstrated that traditional teaching methods are inefficient in eradicating misconceptions. Indeed, it has been observed that without a conceptual change—without learning comprehensively—the knowledge acquired in school is fragile and fleeting.

The 5E Model aims to lead learners to an effective conceptual change, showing them how misconceptions can be overturned and how scientific ideas can be consolidated and become permanent knowledge. Broader, more complex knowledge needs to be built on a solid conceptual framework.

ENGAGE

SUMMARY:

A video presents phenomena in a **familiar** and **meaningful context** and then **exposes a problem or a discrepant event** that puzzles students because they can't explain it with their current ideas. Next, an activity about the video encourages students to **activate their prior knowledge** and **share their current ideas with their classmates**.

OBJECTIVES:

- Present the unit through a real and meaningful situation that engages students and promotes curiosity and interest due to its practical applications.
- **Broaden student interest by creating a cognitive conflict**: the video presents a situation familiar to the student, but which somehow does not fit into their understanding or their current ideas and the students cannot account for it.
- **Activate and elicit student's prior knowledge** and unveil their held misconceptions and conceptual framework concerning the topic to be studied in the lesson.
- **Encourage students to think actively** about the concepts to be treated in the unit, making connections between past and present learning experiences.

APPLICATION:

This phase is best introduced using a projector, rather than students using their devices individually. Students watch the video together, and next the teacher asks questions about the video, promoting and monitoring student participation. Students should be encouraged to share and compare their ideas with other students and express them without being afraid of making mistakes. The students' ideas are heard, and they are thanked for their participation. The point is for students to share their present knowledge before beginning with the unit.

The students can either use a notebook or the printed version of the unit to write down the answers agreed by the whole classroom. Alternatively, the teacher may ask students to use the digital version and write the answers online. This way, students review what has been said in class and allow teachers to have a record of each individual student.

Although the teacher can use the grade sheet to monitor students' answers, the purpose of this activity is mainly to assess student participation and find out what they know about the concept or skill being developed.

Teacher	Student
▪ Plays the video and asks related questions to the whole class to promote reflection. ▪ Leads and monitors classroom discussion throughout the activity. ▪ Encourages students to openly voice their ideas, without being afraid of being wrong. ▪ Guides students' thoughts and classroom discussions. ▪ Highlights students' vague ideas and concepts which lack a scientific basis (misconceptions). ▪ Plays the video one more time if students need to see it again to be able to answer some of the questions. ▪ Ask students to write down the conclusions related to each of the questions. ▪ Explains the meaning of words students do not know.	▪ Carefully watches the video. ▪ Reflects on the situation presented in the video. ▪ Shares their ideas by answering the questions related to the video. ▪ Expresses their opinions and ideas, without being afraid of being wrong. ▪ Engages in discussions with other students about the ideas they do not agree with. ▪ Listens to other students' ideas and shows respect for their opinions. ▪ Requests for clarification of ideas or words that pop up in the activity. ▪ Asks questions about the video or the ideas in it. ▪ Notes down the answers agreed with the rest of the class. ▪ (Reviews the activity at home and goes online to transfer the answers to the digital version of the unit).

EXPLORE +

SUMMARY:

A guided **inquiry-based activity challenges students' initial knowledge and conceptions, and provides opportunities to resolve the puzzlements** of the previous phase. Students investigate phenomena, discuss ideas and make connections. The teacher becomes a facilitator who conducts the activity, listens, observes, and guides students to their understanding. In this stage we can find experiments in videos, lab simulators, interactive explorations, Predict-Observe-Explain activities, etc.

OBJECTIVES:

- Provide opportunities for students to **solve the cognitive conflict** from the previous phase **through inquiry, discussion and critical thinking.**
- **Test the students' own ideas.**
- **Initiate a conceptual change**: students' prior ideas about natural phenomena are reformulated to adapt to concepts that have a scientific basis.
- Help students **construct the unit's main concepts cognitively** by contrasting their prior ideas with new experiences.

APPLICATION:

As with ENGAGE, this phase is best done as a classroom activity. The teacher acts as a facilitator that provides guidance and students are encouraged to express their ideas, hypotheses, and conclusions openly. Questions in this phase are mostly open ended, and the teacher makes sure they are correctly interpreted by students. It is a good idea for students to voice their viewpoints in front of other students, as this promotes cooperative and peer learning.

Some EXPLORE sections contain lab simulators that students will use to make observations and obtain data. At this point, and depending on the experiment, it is important for students to spend some time (about 10 minutes) working individually, in pairs, or in groups collecting data from the experiment. After that, the teacher engages students in a classroom discussion, asking them to share their results by answering the questions following the simulator.

On those pages where information is presented, the teacher should expose the new information orally without reading it out loud directly from the page. The idea is to keep the student's interest in a dynamic oral interaction with the teacher and their peers.

Teacher	Student
▪ Guides students through each of the steps, asking the corresponding questions and showing the resources that are made available. ▪ Encourages student participation. ▪ If necessary, provides guidance for student responses, clarifying the interpretation of open-ended questions. ▪ Guides student's reflections, stressing those ideas or inferences that are correct and can lead them to draw the appropriate conclusions. ▪ Solves students' doubts. ▪ Helps students to reach a consensus regarding their answers and draws the conclusions for each of the steps in the section. ▪ Explains the final conclusions of this activity.	▪ Reflects on the questions posed in this phase. ▪ Reasons out their contributions, whether that means proposing hypotheses, expressing opinions, drawing conclusions, or answering specific questions. ▪ Engages in classroom participation, sharing their ideas openly with the rest of the class, without being afraid of being wrong. ▪ Engages in discussions with other students about the ideas they do not agree with. ▪ Listens to other students' ideas and shows respect for their opinions. ▪ Requests clarification of ideas or words that pop up in the activity. ▪ Writes down the answers agreed with the rest of the class. ▪ (Reviews the activity at home and goes online to transfer the answers to the digital version of the unit).

EXPLAIN

SUMMARY:

The **conceptual content** developed in the previous phase is **formally presented,** as well as other related content. This phase includes **a wide range of multimedia resources** to make richer presentations and facilitate comprehension. Every concept developed in this section is accompanied by interactive exercises that aim at consolidating what has been learned by means of practice.

OBJECTIVES:

- Introduce conceptual content, factual content, and procedural content in the unit through concise, clear **explanations**.
- **Formally define** the scientific concepts achieved through inquiry in the previous phases.
- **Complete** the **scientific knowledge** directly or indirectly related to the situations and experiences in the previous phases.
- Provide a **structured, common framework** for the acquisition of the knowledge in the unit.
- Present **new scientific terminology** and their clear and concise definitions.
- Consolidate factual, conceptual, and procedural learning through **practice**.

APPLICATION:

This phase can have different approaches, and it is down to the teacher to combine them as he or she wishes. If students have access to devices in the classroom, a good idea is to have them working individually (or in pairs) and ask them to read the explanations and do the activities linked to each of the pages in the section. The teacher, who can use the grade sheet to monitor the students' progress, walks around the classroom and attends to individual queries while the class is working on the activities. If the teacher considers it appropriate, they can share a query with the rest of the class and provide a clear explanation, using the unit's resources or any other resources available to the teacher. Additionally, the teacher can select specific content and present it to the students, or solve exercises together with the whole class, especially those including open-ended questions or experimental situations.

Alternatively, the teacher can organize the students into groups and ask them to prepare specific parts of the unit and present them to other groups. Of course, another option is for the teacher to formally explain all the content in this section using the unit's resources, and involve students by correcting the exercises together with the class.

Since most exercises in this phase are self-graded, and often the answers to these exercises involve choosing between several options, teachers are recommended to penalize students attempts from the grade sheet in order to limit simple guessing. In any case, the teacher can know the number of attempts each student makes to solve a given exercise at all times.

Teacher	Student
▪ Presents the unit's content through formal explanations and examples. ▪ Provides clarification for tricky or difficult concepts. ▪ Checks that the exercises are solved correctly together with the class. ▪ Assigns exercises for individual students or groups. ▪ Monitors student progress using the grade sheet.	▪ Pays attention to the teacher's explanations or reads the unit's content by themselves, trying to make sense of it. ▪ Checks with the teacher or other students whatever doubts or questions that may arise. ▪ Solves the problems posed in the related activities conscientiously. ▪ Tries to provide their own explanations, without having to recite the content in this section from memory.

ELABORATE

SUMMARY:

This stage includes a **project-based** activity. This activity requires the **application of concepts, attitudes, and procedures** learned by the students in the unit, in order to **solve a new problem in a new context**.

OBJECTIVES:

- Provide opportunities for **use and application of newly acquired knowledge** that helps students solve a problem or situation by means of **preparing a project**.
- **Consolidate the conceptual change** through the use and application of scientific concepts in new contexts and new situations.
- **Promote student cooperation** and team work.
- Introduce students to the use of **external resources** for scientific projects.

APPLICATION:

The teacher has students work in groups, and each group is assigned a task. Some of the work will have to be done outside the classroom, and the groups have to make a final presentation of their project.

The teacher should make sure that students are aware of what is actually being assessed with this task and that students are familiar with the teacher's expectations.

The projects can take various forms, depending on the unit: slide presentations together with detailed instructions of how the content must be treated; reports; informative posters; articles; videos; blogs; building models or objects; or experimental designs. On some occasions, students are asked to use free and open source software to complete their projects.

The projects are evaluated on the basis of how well the students have internalized the unit's main concepts. The teacher will provide feedback: indications as to how to improve on the project, highlighting the aspects of the unit that need strengthening.

On some occasions, the ELABORATE section may include questions aimed at complementing the project evaluation.

ATTENTION: due to scheduling issues, or based on the teacher's decision, this phase can be skipped as an exception provided that the activities in the EXPLAIN section have been worked on thoroughly. It is down to the teacher to decide, considering the resources and time available, whether the project is worth doing.

Teacher	Student
▪ Presents students with the task. ▪ Organizes students into groups. ▪ Informs students about deadlines and presentations. ▪ Shares with students what is being assessed and their own expectations about the results. ▪ Corrects the projects and gives feedback and tips on how to improve on their projects. ▪ Evaluates students, focusing mainly on the students' mastering of the scientific concepts involved in the task.	▪ Uses and applies new knowledge from the previous phases to solve a problem or meet a need. ▪ Works collaboratively in groups to resolve a problem using the unit's concepts and procedures, helping their peers to overcome whatever difficulties they may encounter. ▪ Carefully listens to the specific indications given by the teacher and their evaluation criteria regarding the task. ▪ Uses scientific language in various means of communication to talk about data or express ideas and conclusions and justify them considering points of view other than their own. ▪ Reviews and considers the teacher's correction and indications given after the evaluation.

EVALUATE

SUMMARY:

A video goes over the main concepts taught in the unit as a **final revision**, which are summarized in a concept map. Next, **a self-correcting test based on the principles of competencies assessment** evaluates the students' ability to apply the learned knowledge and procedures.

OBJECTIVES:

- Provide students opportunities to **review and reflect** on their ideas and understanding of the concepts learned throughout the unit.
- **Obtain positive evidence** of the students' conceptual change.
- **Assess the students' development of new competencies** derived from the integrated acquisition of factual, conceptual, procedural, and attitudinal knowledge.
- Carry out both a **summative and formative evaluation**.

APPLICATION:

The video in this section can be used to close the unit or as a last chance to review and reflect comprehensively on the knowledge acquired.

This stage provides a test that students must take individually. The test is not common in a traditional sense. Rather than being an accurate evaluation of the students' factual knowledge, the test focuses on the students' ability to solve a problem by applying the new knowledge in new situations. Therefore, what is being truly assessed is how new knowledge is integrated comprehensively, as this leads students to develop new scientific competencies effectively (in line with the type of evaluation proposed by the PISA tests).

Students can take these tests using their notes, coursebooks, or the Internet... They can even use the Science Bits learning unit. Students may be required to look up and use new information together with their present knowledge to solve the problems posed in the test questions.

Taking Science Bits' tests for the first time may be tricky for some students, since they are not accustomed to this type of assessment. It is therefore important to prepare students for these exams—simply memorizing the unit's content will not work here. After grading the first few tests, we strongly recommend that students review it together in class with the teacher or even have the chance to take it again as part of their homework.

From the grade sheet, the test results can be weighted as part of the final average grade, together with the exercises from the EXPLAIN section and the project from the ELABORATE section (if applicable).

Teacher	Student
▪ Uses the unit's video to promote reflection on what has been learned throughout the unit and try to solve any last-minute doubts before the test is taken. ▪ Explains the assessment criteria and the type of questions included in the test. ▪ Helps students prepare for the exam. ▪ Gives feedback by reviewing the test in class and, if necessary, gives more tips on how to prepare for this type of exam.	▪ Reflects on the understanding of the concepts tackled in the unit. ▪ Prepares for the exam focusing on the understanding of new concepts and acquisition of key factual, conceptual, and procedural knowledge. ▪ Answers the test questions using their knowledge and external resources. ▪ Assesses their own progress and knowledge. ▪ Considers the feedback given by the teacher and other students while doing the test revision in class.

*To learn more about the Evaluate phase, please read the article ***Evaluation at Science Bits*** (see annex).

= teacher-guided = teamwork = student-independent

Annex 1

Research-based strategies for teaching science to students with special needs

The terms 'special education needs' and 'special needs' commonly refer to students who require additional support for learning and instruction. For this guide, we aim to focus on students including English learners, students with cognitive disabilities, students living in poverty and female students. For other students in need of differentiation such as advanced learners, Science Bits provides "enrichment" activities in every lesson that teachers can assign them to foster and strengthen their science learning.

Students with special needs tend to show significantly lower achievement in science than their peers. Reasons for this include severe difficulties with academic skills (i.e. reading, math and writing), behavior problems and limited prior understanding of core concepts background knowledge. Despite this bleak picture, much is known on how to significantly improve science achievement for students with special needs. Research indicates that some teaching practices such as guided inquiry instruction, which infuses appropriate scaffolds and supports, can significantly improve science achievement for students with special needs. These are the kind of instructional practices that Science Bits offers by following the 5E model of instruction.

English Language Learners

The science classroom is often a frustrating place for English language learners. Science has a complex vocabulary that is difficult even for native English speakers to learn. Difficulty learning English should not be confused with an inability to think scientifically. Many of the strategies that are useful for English language learners are effective for differentiating instruction for other students as well. These strategies must be grounded on research.

The California English Language Development Standards summarize some of the key findings from research on English learner literacy that have relevant implications for foundational literacy skills instruction for ELs. These key findings and their implications are:

English learners benefit from Reading Foundational Skills instruction.

Research Findings: Instruction in the components of reading foundational skills—such as phonemic awareness, phonics, fluency, vocabulary, and text comprehension (NICHD 2000)—benefits ELs.

Implications: Instruction in foundational literacy skills is essential for ELs. However, the instruction should be adjusted based on students' spoken English proficiency (they may or may not be familiar with the English sound system) and native language or English literacy proficiency (they may or may not be familiar with any type of writing system or with the Latin alphabet writing system in particular). Note that some ELs at any age may not be literate in any language when they arrive in the U.S. school system; their native language may not have a written form, or they may not have had opportunities to develop literacy in their native language or in a local language of wider communication.

Oral English language proficiency is crucial for English literacy learning.

Research Findings: Oral proficiency in English (including oral vocabulary, grammar, and listening comprehension) is critical for ELs to develop proficiency in text-level English reading comprehension. Word-identification skills are necessary, but not sufficient.

Implications: Instruction for ELs in oral language knowledge, skills, and abilities must be explicit, intensive, and extensive. In order to be successful in reading English, ELs must develop proficiency in listening and speaking skills in English—depth and breadth of vocabulary, as well as grammatical structures—at the same time that they are developing foundational skills in reading and writing English.

Native language literacy skills facilitate English literacy learning.

Research Findings: ELs' native language literacy skills can help them learn English foundational literacy skills.

Implications: Instruction for ELs will need to vary based on variations among ELs' native language writing systems, as well as ELs' experiences with literacy in their native language. For example, students who are literate in a language that uses the Latin alphabet (such as Spanish) will be able to transfer decoding and writing skills more easily than a student who is literate in a language with a non-Latin alphabet (such as Arabic, Korean, or Russian) or a language with a symbol-based writing system (such as Chinese). Similarly, students who are literate in a language related to English (such as Spanish) will be able to use knowledge of cognates (words with similar meaning and spelling in both languages), whereas students who are literate in unrelated languages (such as Arabic, Chinese, or Korean) will not.

Based on the previous key findings, we recommend teachers to use a variety of methods when implementing Science Bits in the classroom:

Listening

- **Speak slowly, distinctly, and write down key terms:** Anyone who has learned a foreign language in class, then traveled to a country where the language is spoken, has noticed that it is difficult to understand natives because they seem to "talk too fast". What seems normal speed to a native speaker is extremely fast to a language learner or to a student with a hearing impairment. The addition of the complex terms and concepts of science can make learning even more difficult. Write down key terms so students can see them and connect them to the spoken word.
- **Closed Captioning:** All Science Bits' videos are equipped with closed captioning. Turn on the closed captioning so students can see what narrators are saying. This helps English language learners correlate written and spoken English, and helps them see spelling and sentence construction. Closed captioning is also invaluable for the hearing impaired.

Visualization

- **Emphasize visual literacy:** It is often said that math and music are universal languages –ones that can be read regardless of one's primary language. Although these claims are debatable, it is clear that an English-speaking student can read and understand an equation in a Swahili textbook, and a Greek musician can play a score drafted by a Japanese composer. Regardless of linguistic background, people around the world can interpret mathematical equations and musical scores. In addition, they can also interpret pictures, and with minimal linguistic skills, can interpret charts and graphs. Visual literacy, or the ability to evaluate, apply, or create conceptual visual representation, is relatively independent of language, and is therefore invaluable to learning science and English simultaneously. Videos, animations, pictures, diagrams are a few of the many visual resources that Science Bits includes in every lesson, which can be used to build visual literacy.
- **Graphic Organizers:** Graphic organizers are a means of introducing and assessing concepts in a manner that encourages meaningful learning. Graphic organizers are diagrams or maps that show the relationship between new and existing concepts, thereby facilitating integration of new and familiar ideas. They require minimal language and are therefore helpful tools when teaching science to English language learners. Concept maps and mind maps are some of the common graphic organizers offered in every Science Bits unit.
- **Charts, graphs, and figures:** Charts, graphs, and figures can communicate concepts with minimal use of spoken or written language. Many Science Bits activities are supported by these kind of resources.
- **Manual video control:** Science Bits' videos often introduce a variety of new terms and concepts, most of which even native speakers never remember. You can pause the video to discuss key concepts. Use the bookmark and video clip features to return to precise sequences for review. Use the step-frame and replay features to focus student attention on key concepts.

Interpersonal strategies

- **Group projects & cooperative learning:** Many of the activities in Science Bits employ group work and cooperative learning, especially in the Elaborate stage. Such activities provide opportunities for students to exchange, write, and present ideas. Projects use a variety of skills that work together to increase understanding and retention.
- **Partner English learners with strong English speakers:** The best way to learn something is to teach it. Partnering English learners with strong English speakers benefits both. It may be particularly beneficial to pair English learners with bilingual students who can translate laboratory and activity procedures. Develop your seating chart so English language learners are sitting near the front of class and adjacent to bilingual students who can assist them.
- **Think/Pair/Share:** Students learn to speak English by speaking English, but it is often counterproductive to ask English language learners to read passages or give descriptions to the entire class. Students are often embarrassed by their minimal science knowledge and English skills, and public exposure may make them more uncomfortable and reserved. By contrast, English language learners are often eager to share their ideas in their new language with their peers. The think/pair/share strategy gives all students the opportunity to practice English by explaining science concepts. Provide students with time to write a response to a thought provoking question (e.g. the question posed by the video of the Engage stage), then additional time to discuss it with their neighbor before sharing their conclusion with the class. The think/pair/share technique increases student participation and involvement, and is a particularly effective way of encouraging English language learners to express science concepts in English.
- **Encourage participation:** Many English learners come from countries in which student participation is not encouraged. They may be reluctant to speak, not only because of their lack of proficiency in English, but also because of they are uncomfortable in an environment where they are asked to share their ideas. A positive and supportive environment has a significant influence on student comfort level, participation, and success. Requiring English language learners to speak in front of class may be counter-productive and cause great anxiety. Encourage them to express themselves, but don't force them onto the stage prematurely.

Structure

- **Consistent routines:** English learners are freer to concentrate on new concepts if they are familiar with classroom routines.
- **Road map to science:** English language learners benefit greatly from a "road map" that shows where they are in the science curriculum. Use the organizational tools provided by Science Bits' platform when teaching to English language learners.
- **References:** Provide students with explicit references of Science Bits' content that you plan to use in your class. This will help ELL students know where you are, and where you are going with your lesson.
- **Relate to prior knowledge:** Make use of student background knowledge of science concepts. Spend enough time with the activities at the cover of every unit and the Engage activity to discover what your students already know about a given topic and build upon this knowledge.

Laboratory and simulators

- **Hands-on activities:** Kinesthetic learning events (in real settings or by means of virtual simulations and interactivities) provide an excellent learning environment for English language learners. Science Bits provides multiple hands-on activities of benefit for English language learners.

Demonstrations

- **Clear, procedural steps:** The science laboratory can be a confusing and potentially dangerous setting for English language learners. Present procedures clearly using flow charts, pictures, and outlines. In addition, Science Bits provides videos with lab procedures and simulators that allow you to introduce materials and procedures before heading to the laboratory.

- **Model laboratory activities:** Demonstrate activities in front of class or use the videos and simulators provided by Science Bits to ensure that English language learners can see the procedures before engaging in an activity.
- **Visual guides:** Science Bits provides videos and step-by-step animations that clearly explain lab procedures and safety practices.

Reading and Writing

- **Journaling:** Students become better writers by writing. Require English language learners to keep science journals in which they write lecture notes, new terms, and responses to prompts. Science Bits includes many open-ended questions, mainly in the Engage and Explore stages, that English language learners must fill in for you to keep track of their writing.
- **Science reading comprehension activities:** Every Science Bits unit includes several activities (in the Explain stage) for developing and assessing reading comprehension, and can be used when making formative assessments of language and science learning.

Instruction

- **Wait time:** Teachers are often uncomfortable with silence and either call on the first student to raise their hand, or answer questions themselves, thereby short-circuiting the thought processes of most students, particularly English language learners who are trying to translate terms while formulating an explanation. Let students know that you expect all to be mentally engaged, and for this reason you provide wait-time sufficient for the majority to develop an answer before calling on any individual. This will be especially important during the Engage and Explore activities.
- **Analogies:** Use analogies to relate new concepts to previously learned concepts. Science Bits provides analogies for specific concepts that are especially difficult to understand (e.g. electricity, energy, etc.).

Vocabulary

- **Language-based science activities:** Reinforce vocabulary with activities that consist in classifying virtual cards, fill in blanks in diagrams, complete sentences with appropriate words, etc.
- **Picture glossary:** One of the best ways to learn the vocabulary of a new language is with pictorial flash cards. A picture of the concept is on one side while the term (in the language to be learned) is on the reverse. The student learns to correlate concepts directly with words, eliminating the need for translation.
- **Common lexicon:** People construct understanding by integrating new ideas with preexisting knowledge. Ask students what they already know, then develop a common classroom vocabulary that can be used to develop new understandings.
- **Root words:** A knowledge of Greek and Latin prefixes, suffixes, and roots can greatly enhance student understanding of scientific terms and facilitate a better understanding of English and other European languages. Approximately 50% of all words in English have Latin roots, many of which are shared with Spanish, French, Portuguese and Italian. Learning scientific root words thereby helps one understand the vocabulary of a variety of languages, particularly English.
- **Cognates:** Many science terms are used internationally. Identify such terms and ask your students to notify you whenever they recognize a new term that is pronounced or written similarly in their first language. This helps build your knowledge of cognates (words that are similar in two or more languages) so you can help future learners master science vocabulary.
- **Mathematics translation:** English language learners find word problems much more challenging than symbolic math problems. The English language is exceedingly complex, with numerous nuances that must be learned. Students need to be able to translate common words to math symbols, natural language to algebraic expressions, and algebraic expressions to natural language. The activities in Science Bits help students develop such skills.
- **Word wall:** Post new vocabulary terms on the wall in an organized, grouped manner. For example, you may wish to post new biology terms in columns according to the level of organization (cell, tissue, organ, system, etc.).

Students with cognitive disabilities

Teaching science to students with cognitive disabilities in inclusive classrooms is a challenging task for science teachers. It appears that these students continue to fall behind their non-disabled peers in regular education classrooms in many subjects, including science. However, collaboration among teachers, setting high learning goals, effective teaching strategies, and providing some basic modifications can help students with cognitive disabilities be more engaged and succeed in science classes.

The research-based strategies that Science Bits recommends for students with cognitive disabilities are:

- **Collaboration among teachers:** Collaboration among teachers is important as science teachers might have difficulty to have adequate skills in individualizing instruction for students with all types of disabilities and needs. On the other hand, it might be quite challenging for special education teachers to be experts in science content. Therefore, collaboration between science teachers and special education teachers can help both groups to address the educational needs of students with special needs in middle school science classrooms. Teaming up with another teacher can help science teachers to implement and generalize those strategies across subjects and classes for students with special needs.

- **Setting goals:** Students with special needs can improve their motivation and achievements by setting goals for their science class. Beside the goals that every Science Bits' unit makes explicit as a leading question around specific natural phenomena, goals for students with special needs must include effective study strategies to improve test grades or editing lab reports for understanding the science content. Focusing on these goals will help students with special needs to progress towards their goals and have a feeling of control in their learning.

  Researchers suggest that setting up goals in science class may lead to other educational goals, which increase the student's achievement and motivation in all classes. These goals may help students with special needs increase their performance and continue to strive for strong learning and academic achievement. However, it is crucial for science educators to reconsider the ability of mixed groups when setting classroom goals. The abilities of the students may differ based on home influences, prior experiences, and differential treatments by teachers.

- **Different instructional approaches:** Students with special needs benefit from different instructional approaches in science classrooms as these strategies help science instructors to differentiate and individualize their instruction.

Individualized attention to students with special needs allows science instructors to provide more choices that are based on different learning modalities in order to make instruction and evaluation more meaningful. The richness of the teaching methods is likely to make the new teaching items more attainable and interesting for students. Such variety in teaching practices can enable educators to help students with special needs succeed in writing a variety of reports, observing, discussing, participating in group activities (e.g. sharing data and ideas), creating websites, doing hands-on activities, and reflecting.

The use of different teaching strategies can be implemented by science teachers thanks to the different types of activities offered by Science Bits. These strategies must be applied not only to teach the science content, but also to teach students how to study and learn science. This method is not only crucial for students with special needs, but also for all students without disabilities who need assistance in reading, learning, memorizing, and organizing difficult science content.

Some of the effective teaching methods for students with special needs include inquiry-based learning and cooperative learning.

- **Inquiry-based learning:** Inquiry-based learning involves problem solving and critical thinking skills to arrive to conclusions. This teaching strategy is student-centered. By using this method, students with special needs can improve their skills of observing, measuring, classifying, inferring, hypothesizing, engaging in controlled investigation, predicting, explaining, and communicating. In addition, research shows that inquiry-based learning promotes cooperative learning among students from different ability groups in science classroom. Explore activities in each Science Bits unit provide opportunities for inquiry-based learning through learning sequences that offer appropriate scaffolds and supports throughout the phase.

- **Cooperative learning:** Cooperative learning involves putting students in small groups and allowing them to work together. Their grouping of students is not based on their ability; instead they come from all levels. Students are expected to complete assigned tasks together. This model enables students to maximize their own and each other's learning.

  It is important for science teachers to ensure that all members in the groups cooperate and have positive effects on one another. Research supports cooperative learning due to promoting cognitive elaboration, enhancing critical thinking, providing feedback, promoting social and emotional development, appreciating diversity, and reducing student attrition.

  Elaborate activities in each Science Bits unit are science and engineering projects that provide opportunities for cooperative learning.

- **Homework adaptations:** Homework assignments can be very challenging for most students with special needs in science classrooms. It is helpful when educators provide clear directions and specific oral and written explanations for homework assignments. Science teachers can assist with such assignments during class time, and special education teachers can monitor the progress and ensure that the completed parts of homework are correct. In addition, breaking down homework assignment into smaller segments can also help students with special needs to complete the assignment before the due date.

  - **Assessment adaptations:** One of the challenging tasks for science teachers is to provide modifications in science class as they include practicing test taking strategies and enhancing the performance of students with special needs.

    Collaboration between science teachers and special education teachers is a must as this task requires study time in science class. Teachers can start with a review for students with special needs so that they can focus and understand the importance of assessments in science class. Before starting any assessment, it is crucial that students with special needs are encouraged to preview the entire assessment so they can allocate their time efficiently for each section. It is also important for educators to emphasize common vocabulary that appears on most assessments. For example, some of the most common vocabulary includes describe, explain, compare, contrast, track, support, summarize, analyze, and evaluate.

Students living in poverty

It's clear that children from poverty are often at a disadvantage in school, and educators can find it challenging to help such students become positively engaged in their own learning.

There are a number of ways in which children living in poverty may differ from other children in terms of learning, and it is the responsibility of teachers to help bring about positive changes in students' developing brains to improve their learning ability. Here we provide a number of powerful observations and suggestions for purposeful teaching aimed at improving science learning for learners from poverty:

- **Involve students in problems and concerns vital to their lives:** The "Engage" activity in every Science Bits unit is aimed to provide a real-life context which highlights the related scientific concepts in a way that students find them relevant.

- **Boost engagement:** Students from poverty often need more help engaging in the classroom. To help students become truly engaged, teachers can use cooperative learning strategies such as the ones included in the "Elaborate" stage of Science Bits units.

- **Help students see big ideas and major concepts:** The "Explore" section focuses on the unit's main ideas and helps students build understanding through an active and cooperative inquiry-based activity that provides conceptual scaffolds to help them develop major concepts.

- **Involve students in planning what they will be doing:** Teachers can inform students about the 5E model they will be using to learn science. To help them do that, teachers can use the video entitled This Is How You will Learn Science with Science Bits in "Introductory resources for students." Also,, they can get students to share the units' learning goals and use the rubrics provided in the "Elaborate" section when they are working on projects cooperatively.

- **Get students actively involved in their own learning:** Science Bits' approach to science learning puts students at the center of the learning process. The activities of the "Explore" section in every Science Bits unit provide opportunities for inquiry-based learning, an instructional strategy that is student-centered and promotes cooperative learning among students.

- **Get students involved in real life experiences, field trips, and community work:** The Science Bits project in the "Elaborate" stage offers students opportunities to get involved in building solutions for problems that affect their community. In addition to it, the project connects them to specific local issues that affect natural environment, public health, or social concerns.

- **Build relationships:** At-risk learners are often lacking long-lasting, stable relationships in their lives. They may also require more assistance in developing the full emotional range to respond well to various kinds of stimulation. Discipline issues sometimes emerge when teachers expect more than what students are currently capable of, on an emotional level. Classroom teachers can help students develop a healthy range of emotional responses in order to build healthy, stable, trusting relationships as a foundation for learning.

- **Understand and control stress:** Stress is a physiological response to a perception of a lack of control over an aversive situation or person. At-risk students are likely to have more stress in their lives than other students. Teachers can help increase students' perception of control by encouraging activities like peer mentoring and student jobs in the classroom, as well as offering more opportunities for students to make their own choices throughout the school day.

- **Develop a growth mindset:** Children who are raised in a poverty-stricken environment often need help developing a growth mindset, which places more importance on attitude, effort, and strategy than on luck, genetics, and socioeconomic status. Students who view their cognitive abilities as fixed from birth or unchangeable are more likely to experience decreased confidence and performance when faced with difficulties or setbacks. Students who are more confident about their abilities in science are more likely to perform well.

Female students

Although there is a general perception that men do better than women in science, researchers have found that the differences between women's and men's science related abilities and choices are much more subtle and complex than a simple "men are better than women in science." Several potential reasons for the gender disparity include previous coursework, ability, interests, and beliefs.

Areas where consistent gender differences have emerged are children's and adolescents' beliefs about their abilities in science, their interest in science, and their perceptions of the importance of science for their futures. In general, researchers have found that girls and women have less confidence in their math abilities than males do and that from early adolescence, girls show less interest in math or science careers. In other words, girls, particularly as they move out of elementary school and into middle and high school and beyond, often underestimate their abilities in mathematics and science. However, it is important to note that not all girls have less confidence and interest in mathematics and science, and that girls, as well as boys, who have a strong self-concept regarding their abilities in math or science are more likely to perform well in science.

Theory and empirical research suggest that children's beliefs about their abilities are central to determining their interest and performance in different subjects. One major way to encourage girls to choose careers in science is to foster the development of strong beliefs about their abilities in these subjects–beliefs that more accurately reflect their abilities–and more accurate beliefs about the participation of women in math- and science-related careers.

Below we formulate specific and coherent evidence-based recommendations that educators can use to encourage girls in the fields of science.

- **Teachers should explicitly teach students that academic abilities are expandable and improvable in order to enhance girls' beliefs about their abilities**: Students who view their cognitive abilities as fixed from birth or unchangeable are more likely to experience decreased confidence and performance when faced with difficulties or setbacks. Students who are more confident about their abilities in science are more likely to perform well.

  - ⇨Teach students that working hard to learn new knowledge leads to improved performance.
  - ⇨Remind students that the mind grows stronger with use and that over time and with continued effort, understanding the material will get easier.

- **Teachers should provide students with prescriptive, informational feedback regarding their performance:** Prescriptive, informational feedback focuses on strategies, effort, and the process of learning (e.g., identifying gains in children's use of particular strategies or specific errors in problem solving). Such feedback enhances students' beliefs about their abilities, typically improves persistence, and improves performance on tasks.

  - ⇨Provide students with feedback that focuses on strategies used during learning, as opposed to simply telling them whether they got an answer correct. This strategy encourages students to correct misunderstandings and learn from their mistakes.
  - ⇨Provide students with positive feedback about the effort they expended on solving a difficult problem or completing other work related to their performance.
  - ⇨Avoid using general praise, such as "good job," when providing feedback to individual students or an entire class.
  - ⇨Make sure that there are multiple opportunities for students to receive feedback on their performance.

- **Teachers should expose girls to female role models who have achieved in math or science in order to promote positive beliefs regarding women's abilities in science:** Even in elementary school, girls are aware of the stereotype that men are better in science than women are. Exposing girls to female role models (e.g., through biographies, guest speakers, or tutoring by older female students) can invalidate these stereotypes.

  - ⇨Invite older girls and women who have succeeded in math- or science-related courses and professions to be guest speakers or tutors in your class.
  - ⇨Assign biographical readings about women scientists, mathematicians, and engineers, as part of students' assignments.
  - ⇨Call attention to current events highlighting the achievements of women in math or science.
  - ⇨When talking about potential careers, make students aware of the numbers of women who receive advanced degrees in math- and science- related disciplines.
  - ⇨Provide girls and young women with information about mentoring programs designed to support students who are interested in mathematics and science.
  - ⇨Encourage parents to take an active role in providing opportunities for girls to be exposed to women working in the fields of science.

- **Teachers can foster girls' long-term interest in science by choosing activities connecting science activities to careers in ways that do not reinforce existing gender stereotypes and choosing activities that spark initial curiosity about science content:** Teachers can provide ongoing access to resources for students who continue to express interest in a topic after the class has moved on to other areas.
  - ➪Embed mathematics word problems and science activities in contexts that are interesting to both boys and girls.
  - ➪Provide students with access to rich, engaging relevant informational and narrative texts as they participate in classroom science investigations.
  - ➪Capitalize on novelty to spark initial interest. That is, use project-based learning, group work, innovative tasks, and technology to stir interest in a topic.
  - ➪Encourage middle and high school students to examine their beliefs about which careers are typically female-oriented and which are typically male-oriented. Encourage these students to learn more about careers that are interesting to them but that they believe employ more members of the opposite gender.
  - ➪Connect mathematics and science activities to careers in ways that do not reinforce existing gender stereotypes of these careers.
- **Teachers should provide opportunities for students to engage in spatial skills training:** Spatial skills training is associated with performance in mathematics and science.
  - ➪Recognize that children may not automatically recognize when spatial strategies can be used to solve problems and that girls are less likely to use spatial strategies than boys.
  - ➪Teach students to mentally image and draw spatial displays in response to mathematics and science problems.
  - ➪Require students to answer mathematics and science problems using both verbal responses and spatial displays.
  - ➪Provide opportunities for specific training in spatial skills such as mental rotation of images, spatial perspective, and embedded figures.

References:

- *California English Language Development Standards*. California Department of Education, 2014.
- *Encouraging Girls in Math and Science: IES Practice Guide*. U.S. Department of Education, NCER, 2007.
- *The sourcebook for teaching science. Strategies, activities, and instructional resources*. Norman Herr. Jossey-Bass 2008.
- Grace Villanueva, Mary & Taylor, Jonte & Therrien, William & Hand, Brian. (2012). *Science education for students with special needs*. Studies in Science Education. 48. 187-215.
- Demirdag, Seyithan. (2014). *Effective Teaching Strategies: Science Learning and Students with Learning Disabilities*. International Journal of Teaching and Education. 2. 45-52.

Annex 2

Evaluation at Science Bits

Science Bits' approach to student assessment in the last section of its 5E methodology is not common in a traditional sense. If seen from a traditional perspective, one may think that their exams often include questions about topics which haven't been covered in the units. Indeed, these exams pose new challenges or problems that may be solved by applying the newly acquired knowledge… provided that this knowledge has been integrated comprehensively. In new situations, the newly acquired concepts can only be used effectively if they have been properly understood. Rather than simple memorization, the ability to put new knowledge into use is the indication that genuine learning is taking place.

Therefore, and in line with its active, skills-based learning proposal, it is worth stressing how Science Bits approaches learning assessment. In Science Bits' exams, students are not expected to memorize scientific knowledge, but rather to solve problems by actively applying scientific concepts, procedures, and attitudes. These exams, like the OECD's international student assessment tests (PISA), bring different competencies into play, not only the ability to memorize data and procedures.

For these exams, students are not expected to simply recite facts from the course book from memory, but rather to show that they have understood these facts and can apply them to solve problems effectively.

To get a clearer picture, students can take these tests using their notes, course books, or any resources that may be available. Indeed, during the exam the Science Bits learning unit is available at all times (students have access to it). Additionally, they can also use the Internet. In fact, access to the World Wide Web is essential to solving the test questions.

Therefore, some of the test questions require students to be tested in what the OECD and PISA call *Digital Competence*: the ability to look up and find information on the Internet and use this information combined with the students' own knowledge to solve a problem. For example, a test question in the *Formed by Cells* unit starts by informing students that antibiotics are drugs used to specifically attack the walls of prokaryotic cells. Next, students are given a list of diseases and have to select the ones that can be treated with antibiotics. In this unit students have learned about the different types of cells and the living organisms that have them. Of course, they do not know what causes these diseases. But they only need to do a quick search on Wikipedia to find out, for example, that malaria is caused by a parasitic protist. Then, the student must remember that protists have eukaryotic cells and infer therefore that antibiotics cannot be used to treat this disease (which is a relevant piece of knowledge for everyday life). In short, to complete a 5E unit test, students have to think: it is not just their ability to memorize facts which is assessed, but also their ability to apply these facts and thus demonstrate understanding.

In a traditional exam, an analogous question would have required students to write down the characteristics of the prokaryotic cell. Most students solving this question have just memorized the facts from their course book, and many of these will forget them shortly after the exam. This is not the type of learning that Science Bits promotes. Our project is based on developing scientific skills because science is not a body of immutable facts that have to be memorized (actually, scientific knowledge is constantly evolving), but an exciting way to obtain new knowledge and understand the world around us, with a critical mind and a proactive attitude. We believe this type of scientific learning is useful and beneficial for all students, regardless of the career path they choose.

Obviously, not all students are used to this type of assessment. Some may even say that it appears to be more difficult. In reality, the assessment is not more difficult; it is simply different. Students cannot pass these tests by merely memorizing facts from the course book and reciting them from memory. They need to integrate the new concepts, understand their implications, and use their thinking ability to be able to apply them effectively to new situations. That is why we recommend that special attention be paid to the "Evaluation" section when students use Science Bits for the first time. One of the best ways to prepare students for these tests is to work on the unit thoroughly and do the linked activities from the "Explain" section. Indeed, many activities in this section are similar in nature to the test questions.

Additionally, we recommend that the first tests taken with Science Bits are also used as learning tools, not only as evaluation tools. That is, students need to learn how to tackle these types of tests. These tests, by the way, are more akin to what life has in store for us than those proposed by traditional exams. We strongly recommend that students review the test together in class and solve the questions with assistance from the teacher. In this way students realize that the test was not that difficult after all; it was only a matter of "opening their minds", noticing the resources at their disposal, and effectively using their own skills to solve the questions posed. Once the exam has been graded and reviewed, we think it is a good idea to let students take the test again, but this time from home: the teacher can reset the exam and have students take it as part of their homework.

With this type of assessment, however, it is important to be consistent and not to give in. We know from experience with thousands of schools around the globe that the initial misgivings are eventually overcome and that this test method finally becomes a favorite among students. In fact, most end up admitting that they wished all subjects were assessed in this way.

In our present world, access to information and knowledge knows no boundaries (whether from a reliable or unreliable source). Both the critical ability to discern between appropriate and inappropriate information and the ability to use this information to effectively solve personal or work-related problems are skills that still need to find their space in education. This is the philosophy behind our science teaching and learning project, and the way we choose to evaluate students is in line with its underlying principles.

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