WP3| D3.4

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Work Package 3 | Deliverable 4

D3.4 (D3.0) Guide for developing ESTABLISH Teaching and Learning Units

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A. Background to this report

This report is a deliverable of Work Package 3 (WP3) of the European FP7-funded project "European Science and Technology in Action: Building Links with Industry, Schools and Home" (ESTABLISH; 244749, 2010-2013). It present an additional deliverable 3.4 (also referred to as D3.0) on a Guide for developing ESTABLISH teaching and learning units as developed by the beneficiaries of ESTABLISH. (See Table 1 below for beneficiary list).

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For further information regarding ESTABLISH please contact:

Dr. Sarah Brady (ESTABLISH project manager)

Email: sarah.brady@dcu.ie

ESTABLISH website: http://www.establish-fp7.eu

B. The ESTABLISH consortium

Beneficiary short name	Beneficiary name	Country	Abbreviation
DCU	DUBLIN CITY UNIVERSITY	Ireland	IE
AGES	AG EDUCATION SERVICES	Ireland	IE
UCY	UNIVERSITY OF CYPRUS	Cyprus	CY
UmU	UMEA UNIVERSITET	Sweden	SE
JU	UNIWERSYTET JAGIELLONSKI	Poland	PL
CUNI	UNIVERZITA KARLOVA V PRAZE	Czech Republic	CZ
AL	ACROSSLIMITS LIMITED	Malta	MT
UPJS	UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH	Slovakia	SK
COUO	CARL VON OSSIETZKY UNIVERSITAET OLDENBURG	Germany	DE
UTARTU	TARTU ULIKOOL	Estonia	EE
UNIPA	UNIVERSITA DEGLI STUDI DI PALERMO	Italy	IT
MaH	MALMÖ UNIVERSITY	Sweden	SE
IPN	LEIBNIZ-INSTITUT FUER DIE PAEDAGOGIK DER NATURWISSENSCHAFTEN UND MATHEMATIK AN DER UNIVERSITAT KIEL	Germany	DE
CMA	CENTRE FOR MICROCOMPUTER APPLICATIONS	Netherlands	NL
MLU	MARTIN LUTHER UNIVERSITAET HALLE-WITTENBERG	Germany	DE

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I. ESTABLISH INQUIRY-BASED SCIENCE UNITS

1. Designing principles

ESTABLISH Inquiry-Based Science Units will serve as exemplary material for teachers during a professional development track. ESTABLISH aims to provide materials for a broad range of situations:

- different subjects,
- different levels of education/age groups,
- different educational settings (schools and informal settings), and
- different experience of teachers with IBSE and links to industry.

ESTABLISH Inquiry-Based Science Units must be representative of Inquiry Based Science Education (IBSE) and should show teachers benefits of IBSE in classroom practice and inspire them to generate their own IBSE materials. Therefore an ESTABLISH Unit should:

- highlight the IBSE character and importance of the unit,
- provide a science background
- highlight Pedagogical Content Knowledge
- link to real world/industrial applications,
- include series of Student Learning Activities which encourage and facilitate students to be active learners. These activities should have suitable structure and should show different levels of IBSE.

Specific attention should be given on gender issues ensuring that all materials are suited to both genders. Additional adaptations may be required to take into account cultural differences and particular circumstances in each beneficiary country.

2. Unit structure

An ESTABLISH Teaching and Learning Unit is built around selected science themes, for example, 'Disability' or 'Speech Analysis' and designed according to the following structure:

A. Teacher Information
    I. Unit Description
    II. IBSE Character
    III. Content Knowledge
    IV. Pedagogical Content Knowledge
    V. Industrial Content Knowledge
    VI. Learning Path(s)
    VII. Assessment
    VIII. Student Learning Activities
B. Classroom materials

For constructing ESTABLISH Units the Deliverable 1.1 'Framework for IBSE Teaching and Learning Units' should be used.

II. THE SCIENCE INQUIRY-BASED APPROACH

1. What is the science inquiry–based approach?

There are many answers to the question “What is scientific inquiry?” A possible short answer is that it is the systematic and principled process of pursuing and refining explanations for phenomena in the natural or material world.

In the ESTABLISH project proposal, the following definition of inquiry is used, (Linn, Davis, & Bell, 2004):

> “Inquiry is the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments.”

In the *National Science Education Standards* of the National Research Council (1996), this is stated (p. 23) in the following way:

> “Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study.
>
> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.”

The *NSES* actually refers to the way scientists do research and it presents this as an inquiry cycle, which can take many idealized forms such as the ones shown in Figure 1 and Figure 2.

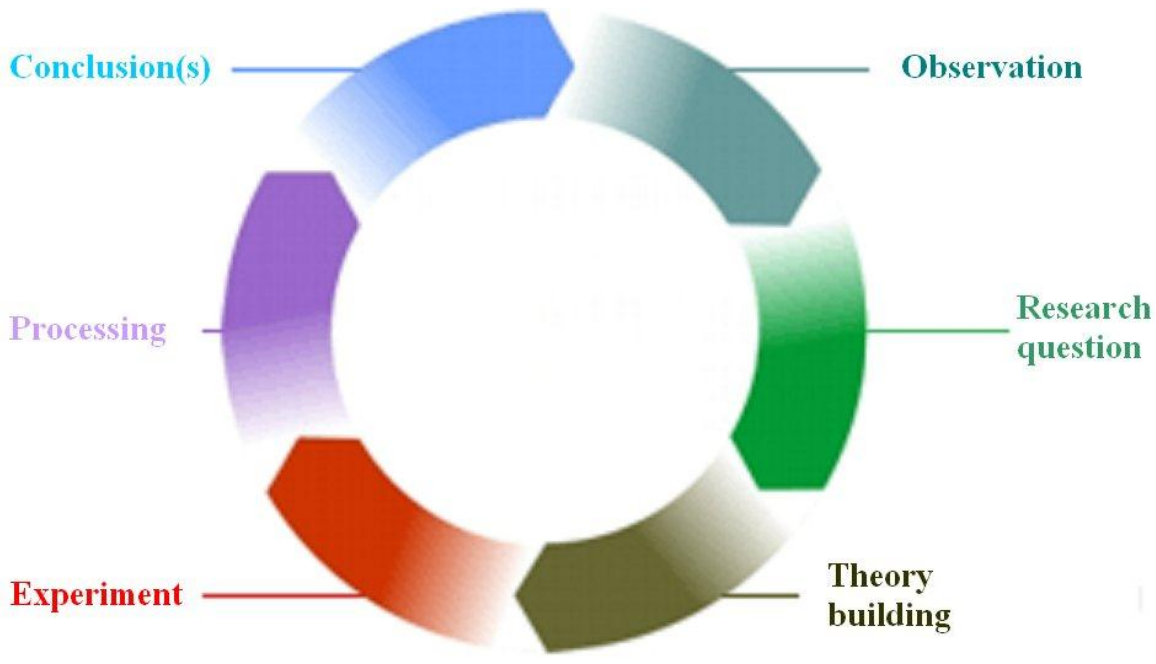

Figure 1. A 6-stage cycle for inquiry investigations and modelling (Bètapartners, 2009; a learning route to inquiry investigations and modelling).

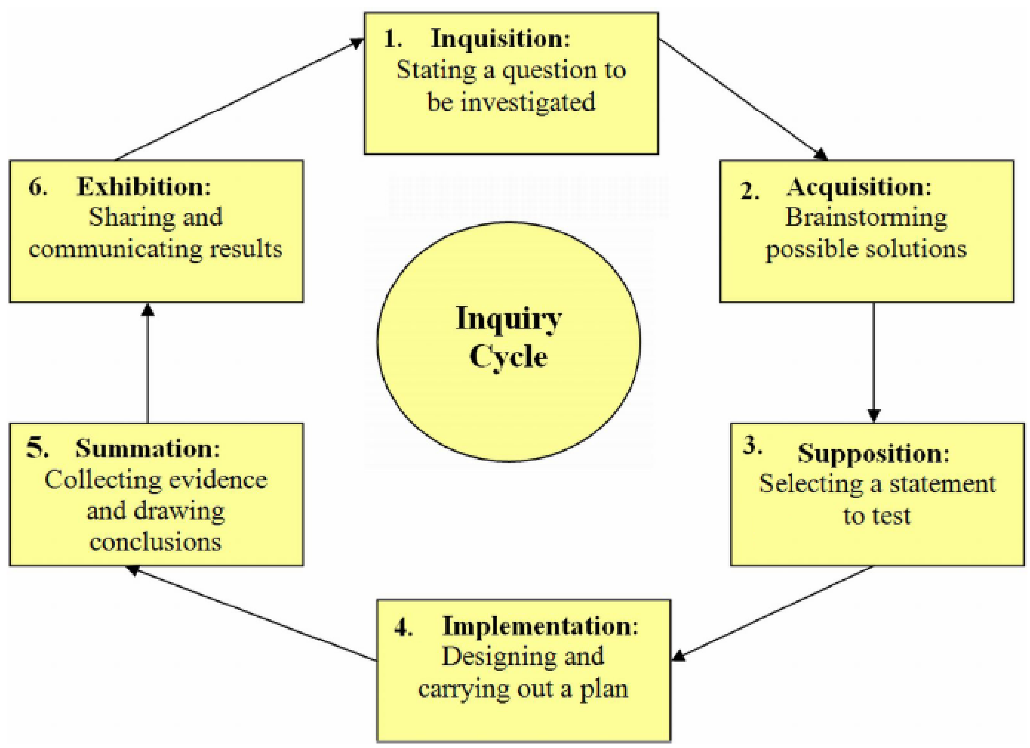

Figure 2. A 6-stage inquiry cycle (Llewellyn, 2002).

Llewellyn (Llewellyn, 2002. p.16) defines inquiry in the following way:

> "To me, inquiry is the science, art, and spirit of imagination. It can be defined as the scientific process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interests. Driven by our curiosity and wonder of observed phenomena, inquiry investigations usually involve
>
> - Generating a question or problem to be solved
> - Choosing a course of action and carrying out the procedures of the investigation
> - Gathering and recording the data through observation and instrumentation to draw appropriate conclusions
>
> As we communicate and share our explanations, inquiry helps us connect our prior understanding to new experiences, modify and accommodate our previously held beliefs and conceptual models, and construct new knowledge. In constructing newly formed knowledge, students are generally cycled back into the processes and pathways of inquiry with new questions and discrepancies to investigate."

In the *NSES* (NRC, 1996) it is also advocated that students at all grade levels get ample opportunity to learn to conduct inquiry and to develop understanding about scientific inquiry. This is stated as follows (p. 105):

> "Science as inquiry is basic to science education and a controlling principle in the ultimate organization and selection of students' activities. The standards on inquiry highlight the ability to conduct inquiry and develop understanding about scientific inquiry. Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments."

In other words, scientific inquiry can be defined both as a learning goal and a teaching strategy. As a learning goal, inquiry includes both the abilities to do scientific inquiry and a set of understanding about scientific inquiry. As a teaching strategy, inquiry-based teaching and learning draw on instructional strategies in which students are physically active and mentally engaged.

Inquiry-based teaching and learning can be organized through various instructional models. Every instructional model reflects more or less the corresponding definition of inquiry cycle. According to Llewellyn (Llewellyn 2004), and many other educators who advocate inquiry-oriented learning, the principles of constructivism are acting as the foundation for understanding inquiry. Llewellyn elaborates in his book on the inquiry cycle of Figure 2 toward what he calls the Constructivist Inquiry Cycle shown in Figure 3.

Constructivist learning theories perceive learning as a constructive and situated process. Each step in the learning cycle of Figure 3 stands for many opportunities for students to search for and construct meaning from the real world and to reflect on experiences. In this approach, students create their own mental models as they make sense of their experiences. They can develop many research abilities and other competencies that are useful throughout their entire life.

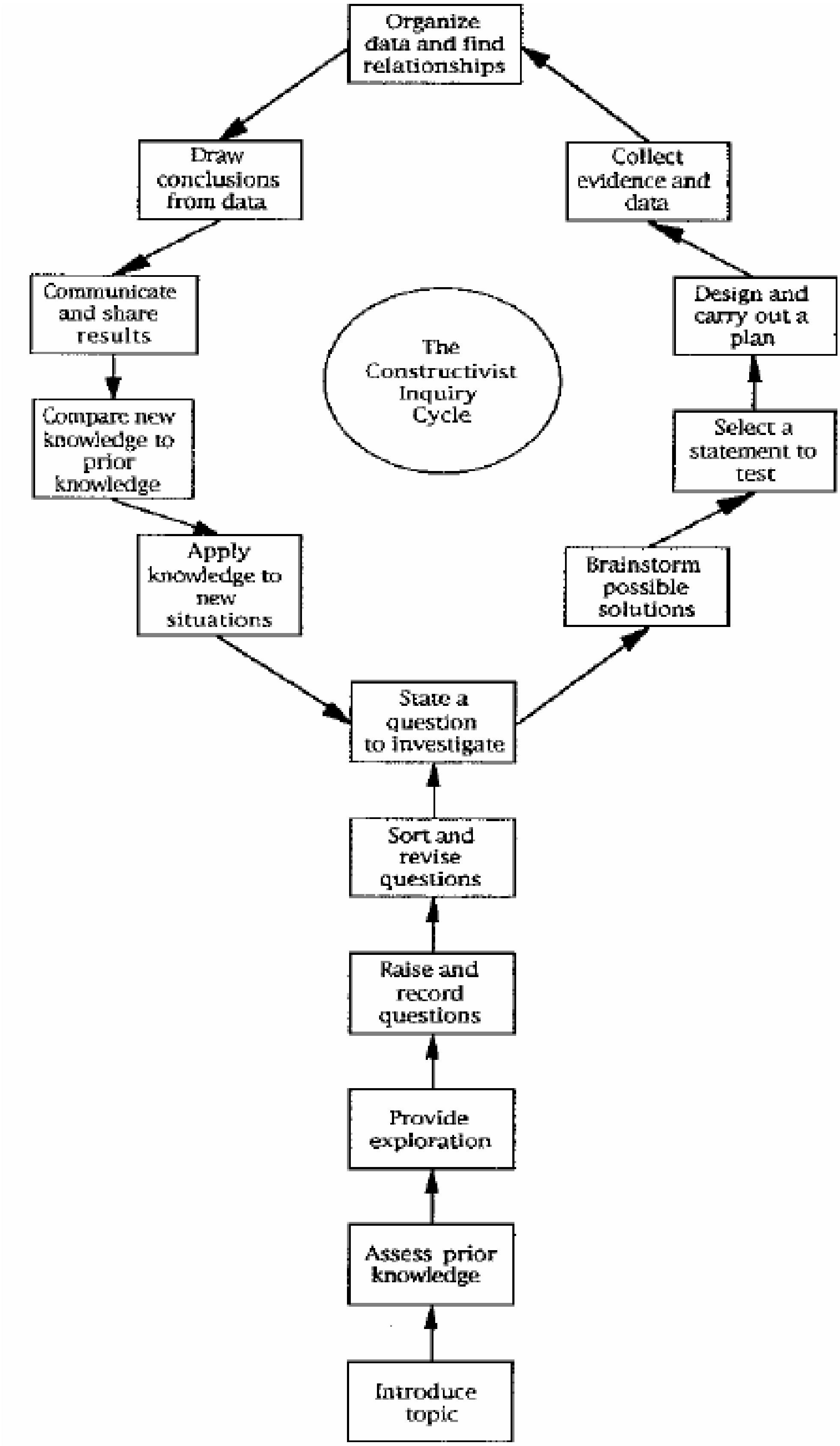

Figure 3. The Constructivist Inquiry Cycle, (D. Llewellyn, 2004).

2. Important principles of the inquiry-based approach

Although there are different types and levels of inquiry-based teaching and learning, it is possible to make some general statements about important differences between inquiry-based science education and traditional science education.

Let us first look at inquiry learning. In the same way that scientific inquiry aims to answer scientists' questions in an evidence-based method, inquiry-based learning of science aims to answer students' questions using a similar clear and rigorous scientific methodology. Research (Branford, Brown, & Cocking 1999; Donovan & Bransford, 2005) indicates that when instruction is designed to engage students in the search of answers to questions that are relevant and interesting to them, their learning improves and they become more motivated. This is also the reason why inquiry learning is quite often positioned in the context of an everyday phenomenon with which students can link up or has personal experience.

In traditional laboratory work the focus of students' activities is mostly on verifying information previously communicated in class by the teacher or in the provided instructional material. In inquiry labs, students' activities are focussing on collecting, processing and analysing data to discover new concepts, principles, or laws in much the same way and with similar tools as real scientists and practitioners conduct investigations. This means that students are given more control of their own learning and consequently it is accepted when things go wrong or not as expected, as long as students learn from mistakes and missteps through reflection and self-assessment; time and opportunity is provided to students to make and recover from mistakes and/or dead-end explorations. Inquiry-based science learning has (at least) three components: learning science concepts, learning to do science, and learning about science.

The role of learners in inquiry-based science learning is summarized in the following list of essential features of classroom inquiry (NRC, 2000, 25):

- Learners are engaged by questions that lend themselves to empirical investigation, and lead to gathering and using data to develop explanations for scientific phenomena.
- Learners give priority to evidence, and use empirical evidence as a basis for explanations about how the natural world works.
- Learners formulate explanations from evidence to address scientifically oriented questions and by doing so they build new knowledge.
- Learners communicate their explanations, thus providing for further sceptical review of the evidence and reasoning behind the explanations.

Inquiry-based teaching is an organized and intentional effort on behalf of the teacher to engage students in inquiry-based learning. The goal of inquiry teaching is not to transfer scientific knowledge, facts, definitions, and concepts, but rather to enhance students' ability to reason and to become independent learners who are capable of identifying main questions and find relevant answers by a gradually acquisition and expansion of a body of scientific knowledge and abilities. It is a student-centred approach to science learning.

The vision of the teacher's role in inquiry-based science education (NRC, 2000, 22-23) has the following six dimensions:

A. ***Teachers of science plan an inquiry-based science program for their students.***

- Select teaching and assessment strategies that support the development of student under-standing and nurture a community of science learners.

- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.
- Work together as colleagues within and across disciplines and grade levels.

B. Teachers of science guide and facilitate learning.

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.
- Challenge students to accept and share responsibility for their own learning.
- Acknowledge student diversity and encourage all students to participate fully in science learning.
- Be a role model of a scientific inquirer by showing curiosity, openness to new ideas and data, and scepticism.

C. Teachers of science engage in ongoing assessment of their teaching and of student learning.

- Use multiple methods and systematically gather data about student understanding and ability.
- Guide students in self-assessment.
- Reflect on and improve teaching practice.

D. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.

- Structure the time available so that students are able to engage in extended investigations.
- Create a setting for student work that is flexible and supportive of science inquiry.
- Identify resources outside the school and make the available science tools, materials, media, and technological resources accessible to student.
- Engage students in designing the learning environment.

E. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.

- Display and demand respect for the diverse ideas, skills, and experiences of all students.
- Enable students to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.
- Nurture collaboration among students.
- Model and emphasize the skills, attitudes, and values of scientific inquiry.

F. Teachers of science actively participate in the ongoing planning and development of the school science program.

- Plan and develop the school science program.
- Participate in decisions concerning the allocation of time and other resources to the science program.
- Participate fully in planning and implementing professional growth and development strategies for themselves and their colleagues.

3. Types of inquiry-based activities

While each complete inquiry activity contains the basic elements of the inquiry model such as the ones given in Figure 1 and Figure 2, it is instructive to introduce a hierarchy of such activities with respect to the level of intellectual sophistication and to student participation or locus of control (Wenning, 2005).

In all types of inquiry activities, the sum of the levels of teacher and student participation will roughly be a constant, indicating that decreasing the teacher activity and participation will generally invite an increase in student activity. Ideally, a teacher should move his students in the course of the study from a teacher-dependent to a more teacher-free and independent role. In other words, the locus of control gradually shifts from teacher to student in the course of studying science at school. This having said, one must realize that the ideal cannot always be achieved, in case of more complex experiments (e.g. detection of cosmic radiation) or experiments that pose a possible safety risk.

To cover the range of types of inquiry activities, we list them below in the order of increasing student participation and independence (locus of control); in reverse, this corresponds to the degree of teacher's guidance decreases.

As a teacher, it is important not to begin at the extreme of full student control, but to enable a student's growing development towards scientific thinking and taking more initiatives in the inquiry process. There will always be goals to meet (set by the teacher), but the formulation and boundary conditions for reaching those goals may vary from guided to bounded to free. Obviously, such a range is not as discrete as presented in the below list of inquiry types, but this list may serve as a tool to be able to recognize the various kinds of inquiry and become aware of their place in the hierarchy. This in turn will allow the teacher to purposely use scaffolding during the course, depending both on the student's skills and level of progress and on the complexity of problems at hand.

1. ***Interactive demonstration**:* the teacher is in charge of conducting the demonstration and manipulating a scientific apparatus, interactively asking probing questions about what will happen (prediction) or how something might have happened (explanation), and helping the students to reach conclusions in a scientifically correct way. The inquiry part here lies in the responses and explanations from the students.

2. ***Guided discovery**:* same as in the above, but in this case the students carry out the experiment introduced to them by the teacher. It is the traditional student laboratory work, mostly in the form of cookbook labs or work driven by step-by-step instructions. Usually, this concerns a group activity simultaneously carried out by the whole class with a strong focus on verifying information previously communicated in class.

3. ***Guided inquiry**:* in this case, students work in teams on their own experiment. The teacher has identified the problem and has given a clear-cut objective: "Find.." "Determine…". There is no predetermined answer and conclusions are solely based on student work. Students are given directions or extensive (pre-lab) instructions, and they are guided by multiple teacher-identified questions.

4. ***Bounded inquiry**:* same as in the above, but in this case students are expected to design and conduct the experiment themselves with little or no guidance of the teacher and only partial pre-lab orientation. Example: "Try to recognize your own peanut from your predetermined

physical characteristics". The research problem to be solved is given to them by the teacher, but they have the responsibility for designing and conducting an experiment. Bounded inquiry activities require a definite level of experience from the students, otherwise they could get lost.

5. ***Open inquiry**:* within a given context, students are expected to propose and pursue their own research question(s) and experimental design. This will usually be a semi-final assignment of senior students. Example: "Setting up an experiment for speech analysis or recognition". Students can either compare high or low tones, male or female, produced by musical instrument or vocally, loud or soft, etc.

The inquiry-oriented science teaching practices 1 to 3 in the above list are completely teacher-initiated, both with respect to the assignment and to the experimental methods to be applied. The pre-lab preparation decreases from comprehensive to partial. In inquiry levels 4 to 5, there are no pre-lab activities. In all cases except in inquiry practice 5, the teacher identifies the problem to be researched by the students.

The listing of essential features of classroom inquiry (section 1 and 2) can be continued along the dimension of level of student guidance and coaching. See for example Table 1 (NRC, 2000, 29), which describes variations in the amount of structure, guidance, and coaching the teacher provides for students engaged in inquiry, broken out for each of the five essential features. It is copied below.

Table 1. Extract from *Inquiry and the National Science Education Standards*: *A Guide for Teaching and Learning* (NRC, 2000, The National Academic Press, p.29).

Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication
More ———— **Amount of Learner Self-Direction** ———— **Less**				
Less ———— **Amount of Direction from Teacher or Material** ———— **More**				

4. Inquiry-based skills

Below we present a non-exhaustive list of inquiry abilities. Note that not all scientific inquiry skills will be used in each investigation. Inquiry based on observation will likely differ significantly from inquiry based on experimentation. Disciplines like biology, chemistry and physics have different approaches to conducting investigations. In addition, not all skills have the same degree of intellectual sophistication, which allows the design of a learning route in which at various grade levels certain abilities are acquired, practiced, and deepened. This is reflected in the listings of the fundamental abilities necessary to do scientific inquiry and the listings of fundamental understanding about scientific inquiry (NRC, 2000, 19-20), which are split for grade K4, grades 5-8, and grades 9-12.

For example, the identified fundamental abilities for grades 9-12:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyse alternative explanations and models.
- Communicate and defend a scientific argument.

Some of these fundamental abilities are expected to be addressed by the teacher at an easier level at earlier grade level. Compare for example the listing for grade K4 level:

- Ask a question about objects, organisms, and events in the environment.
- Plan and conduct a simple investigation.
- Employ simple equipment and tools to gather data and extend the senses.
- Use data to construct a reasonable explanation.

Wenning (Wenning, 2005) suggests the following hierarchy of skills, which is based on the relative degree of sophistication of the inquiry-oriented intellectual processes.

Table 2. Extract from 'Hierarchies of pedagogical practices and inquiry processes', *Journal of Physics Teacher Education Online* 2(3), 3-11.

Rudimentary Skills	Basic Skills	Integrated Skills	Advanced Skills
Observing	Identifying variables	Identifying problems to investigate	Solving complex real-world problems
Collecting and recording data	Constructing a table of data	Designing and conducting scientific investigations	Synthesizing complex hypothetical explanations
Drawing conclusions	Constructing a graph	Using technology and math during investigations	Establishing empirical laws on the basis of evidence and logic
Communicating	Describing relationships between variables	Generating principles through the process of induction	Analyzing and evaluating scientific arguments
Classifying results	Acquiring and processing data	Communicating and defending a scientific argument	Constructing logical proofs
Measuring metrically	Analyzing investigations		Generating predictions through the process of deduction
Estimating	Defining variables operationally		Hypothetical inquiry
Decision making 1	Designing investigations		
Explaining	Experimenting		
Predicting	Hypothesizing		
	Decision making 2		
	Developing models		
	Controlling variables		
Low	← Intellectual Sophistication →		High

The fundamental abilities necessary to do scientific inquiry listed in the NSES Content Standards can be worked out in various ways. For example, in the Pathways to Inquiry project (http://pti.lsu.edu/) at Louisiana State University, the standards for grades 5-8 (listed below) are transformed into the "PTI Inquiry Skill Wheel" (Figure 4) and further elaborated in Table 3. Note that the skill "using mathematical skills" has not been worked out: the focus has been put on narrower use of mathematics within data collection, measurement and analysis.

NSES Content Standards Grades 5-8

- Identify questions that can be answered through scientific investigations.
- Design and conduct a scientific investigation.
- Use appropriate tools and techniques to gather, analyze, and interpret data.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.
- Use mathematics in all aspects of scientific inquiry.

Figure 4. The PTI Inquiry Skill Wheel

Table 3. PTI Science Inquiry Skills

1. Identify Questions for Scientific Investigations

1.1 Identify testable questions

1.2 Refine/refocus ill-defined questions

1.3 Formulate hypotheses

2. Design Scientific Investigations

2.1 Design investigations to test a hypothesis

2.2 Identify independent variables, dependent variables, and variables that need to be controlled

2.3 Operationally define variables based on observable characteristics

2.4 Identify flaws in investigative design

2.5 Utilize safe procedures

2.6 Conduct multiple trials

3. Use Tools and Techniques to Gather Data

3.1 Gather data by using appropriate tools and techniques

3.2 Measure using standardized units of measure

3.3 Compare, group, and/or order objects by characteristics

3.4 Construct and/or use classification systems

3.5 Use consistency and precision in data collection

3.6 Describe an object in relation to another object (e.g., its position, motion, direction, symmetry, spatial arrangement, or shape)

4. Analyze and Describe Data

4.1 Differentiate explanation from description

4.2 Construct and use graphical representations

4.3 Identify patterns and relationships of variables in data

4.4 Use mathematic skills to analyze and/or interpret data

5. Explain Results and Draw Conclusions

5.1 Differentiate observation from inference

5.2 Propose an explanation based on observation

5.3 Use evidence to make inferences and/or predict trends

5.4 Form a logical explanation about the cause-and-effect relationships in data from an experiment

6. Recognize Alternative Explanations and Predictions

6.1 Consider alternate explanations

6.2 Identify faulty reasoning not supported by data

7. Communicate Scientific Procedures and Explanations

7.1 Communicate experimental and/or research methods and procedures

7.2 Use evidence and observations to explain and communicate results

7.3 Communicate knowledge gained from an investigation orally and through written reports, incorporating drawings, diagrams, or graphs where appropriate

The participants of the ESTABLISH project also made their favourite content standard for inquiry-based science education by working out the elements of the definition of inquiry (Linn, Davis, & Bell, 2004). The following initial listing of fundamental abilities have been composed:

i. Diagnosing problems

- Students identify the core of the problems/ questions
- Understand and use their prior knowledge to be able to form working hypothesis

ii. Critiquing Experiments

In order to critique experiments intentionally and effectively, students need:

- Experience
- Analytical skills
- Reflective Skills
- Formulating arguments
- State outcomes in a comparative way
- Suggest further developments

iii. Distinguishing Alternatives

- Identify key elements of the problem
- Identify ranking level for key elements
- Express alternatives in suitable form
- SWOT analysis

iv. Planning Investigations

- Moving from a base of inquiry initiated by student/teacher/other.....
- Establishing the hypothesis in a realistic way towards a goal
- Consider the hypothesis and methods of answering the hypothesis
- Planning involves setting time frame, steps involved, resources required and training in use of any equipment
- Monitor and review of approach

v. Researching conjectures (hypothesis testing)

- Follows from observations/ facts previously gathered and some preliminary theory / hypothesis that is to be tested
- Not just observing but considering why!!
- Open ended

vi. Searching for information

- To define what you need to search using the right resources and how to do this and where
- To identify possible sources of information relating to possible intervening variables

vii. Constructing models

Students try to find something which:

- Enables description, understanding, explaining, prediction
- Can be different types and levels (qualitative, quantitative, computer simulations...)
- May be checked, proved, disproved, adapted, improved, or abandoned

viii. Debating with peers

- Choose the group of science peers (in the class, school)
- Prepare interview including teacher and peer about searching methods, meaning of IBSE, students needs, skills and competencies
- Discussion re different interpretations of experimental results/interpretation/
- Cooperative/collaborative
- Prepare interview teachers and peers...
- Divide class in small groups – according to interests
- Discussion within group – choose 1 peer
- Peer discuss with class group – controlled by teacher
- Class discussion – teacher control, conclusions from discussion

ix. Forming coherent arguments

- Putting forward logical reasons
- This is not inquiry, but can be part of inquiry process in the following way.....
- Students building on evidence/ information so as to be able to present this as a logical, evidence-based communicative format...e.g. Model, solution/conclusion to the process that explains and may include evidence for and against

It is noted that the overlap of the ESTABLISH listing of IBSE elements with Wenning's hierarchy of inquiry skills is smaller than with the elaborated list of PTI Inquiry Skills, for which the overlap is actually quite large.

III. INDUSTRIAL CONTENT KNOWLEDGE

An important aspect of applying science concepts in industry is the goal: in industry most of times the goal is the design of new products or processes, while in science the goal is new knowledge.

A classical idea about the difference between science and technology is the following.

Within science we try to understand the world and within technology we try to change the world. Scientists explore the physical world and develop theoretical models for explanation. This is the arrow from left to right. Engineers or product developers describe a desired world and develop corresponding technical products. This is the arrow from right to left.

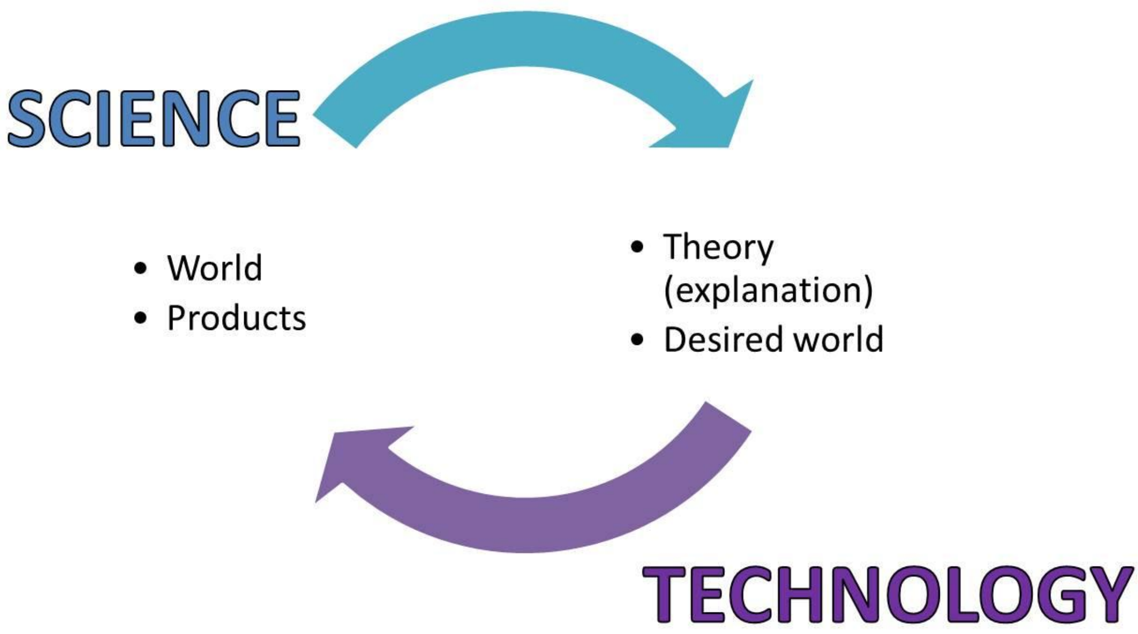

Figure 5: Schematic to describe a relationship between science and technology

The professional practice however is more complex than this scheme suggests. Scientists design technical systems for their research and often engineers do scientific research as part of their product design.

1. Design versus research

Students should be involved in both research projects and design projects. Through these activities they become familiar with the characteristic ways of thinking and problem solving approaches in both science and technology. Science teachers have traditionally sufficient experience with research tasks, but not at all with design tasks. What are the differences and similarities?

As mentioned earlier there is a clear difference in objectives. The objective of science is understanding the physical world, while the objective of technology is changing that world. Connected to this we can say that the yield of a research activity is knowledge, while the yield of a design process is a product. We also define 'quality' in different ways. Where the quality of research is judged by the correspondence with the facts, we can say that the quality of the design is judged by the correspondence with the needs of the focus-group or client.

For students these differences in objectives between science and technology also reflect possible differences in motivation. Researchers are motivated by (abstract) thinking, curiosity and the wish to gain a fundamental understanding of the physical world. Designers are motivated by doing, by the pleasure of creating things, and the wish to elaborate practical solutions for real (human) problems.

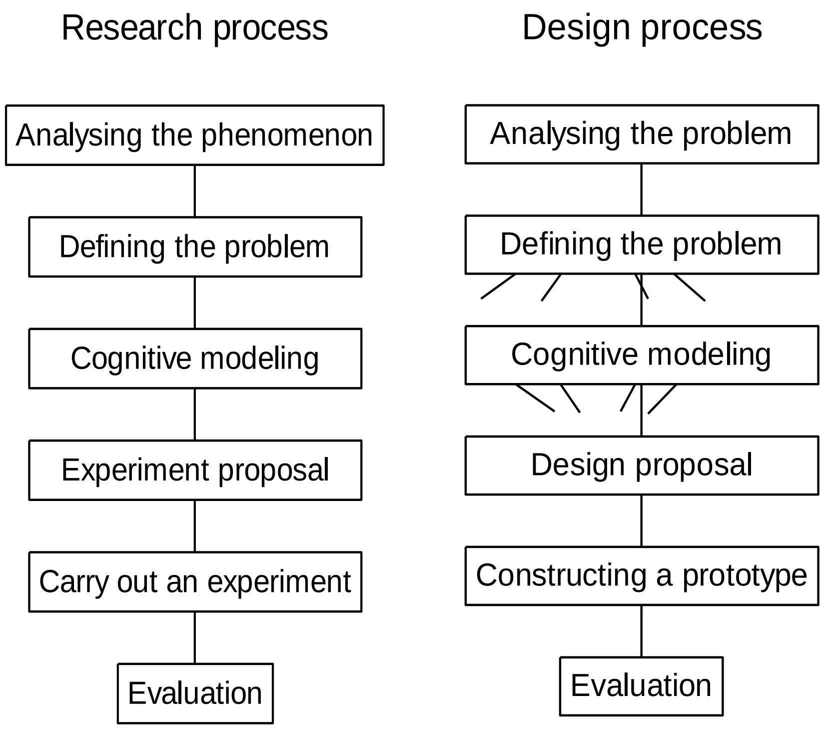

Figure 6: Schematic to compare the research and design process

At first glance the problem solving processes in both domains look similar but there are important differences, especially in the first three stages of the problem solving process (which is in many cases cyclic and not linear as might be suggested by the diagrams!).

1. Analysing the problem

A research problem starts with an orientation on a phenomenon: a mismatch between the theory and the observed facts.

Design problem starts with an orientation on people: a mismatch between the real world and the needs of a focus group or client.

2. Defining the problem

Design problems are ill defined, while research problems are not. Goal criteria are not only ill defined but sometimes even contradictory (Middleton, 2000 [?]). As a consequence design problems include much more uncertainties then research problems.

3. Cognitive modeling

The search for possible solutions starts after the problem is defined.

In research we formulate hypotheses and use existing (school) theory to construct a theoretical model, which enables us to explain the observed facts. The model is used to predict possible outcomes for experimental verification or falsification.

In design the search for solutions is more complex. Where research is dealing with an existing and observable world, in design we are creating a non-existing and not directly observable world. In fact there are many realizable worlds and we don't now which world will give the best correspondence with the needs. We have to make predictions about the 'behavior' of the products to be designed and we never know if we did miss a better solution. In the search for solutions divergent thinking skills are needed.

In the next stages problem solving activities are similar in both domains. In these stages we are concerned with planning, construction and testing ideas. For this kind of activities more vertical thinking skills are needed.

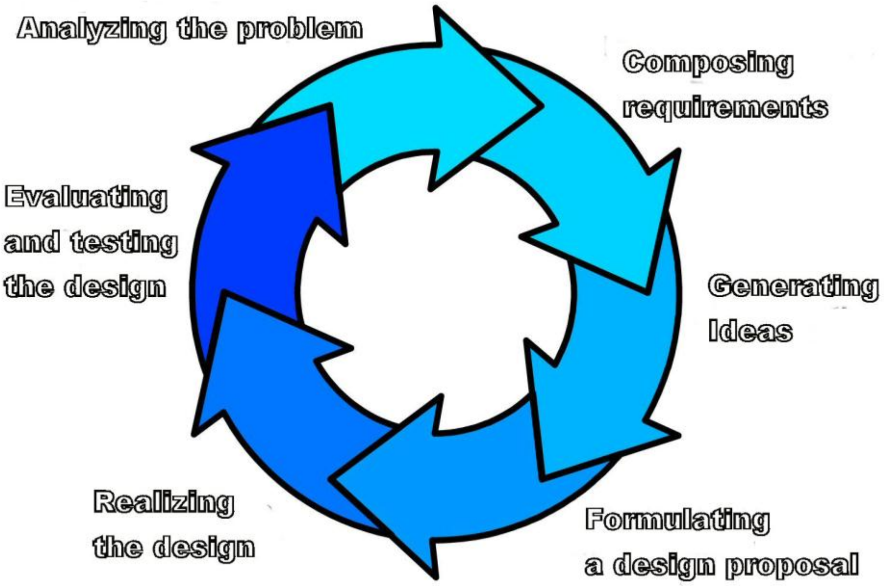

Figure 7. Design cycle

2. Teaching design skills

Based on this analysis we focus in design lessons on the first stages of the design process: problem analysis, problem definition and the search for alternative solutions. Emphasizing on these aspects not only reflects good engineering practice and leads to better designs, but also strengthen the image of technology as a human activity. In this approach doing technology is highlighted as the search for and the realization of concrete solutions for recognizable human needs. These activities not so much require smart and possible narrow minded whiz kids but rather creative students with empathy, communication skills, wide and multidisciplinary interests and a practical mind.

In the phase of **analysing the problem** students must be able to identify one self with the content of the design task and find answers on questions like "what is the problem?", "who has the problem?", "why is it a problem?" and "what do we want to obtain with a possible solution?". Starting point for design projects is always a recognizable owner of the problem. This is important for the conceptualization of technology as a human enterprise and for the motivation of pupils (especially for girls).

In the phase of **problem definition** students must be able to gather design requirements from the previous phase and reformulate general described requirements (e.g. from the client) in testable requirements. The result can be seen as a kind of contract. As a design team they accept the assignment to develop a product that satisfies the requirements.

To strengthen the identification one can work with a real or fictive (e.g. teacher) owner of the problem.

In the phase of **generating ideas** (cognitive modelling) students must be stimulated to consider several solutions. Generating different solutions extends the chance to find one fitting the requirements. This is an important part of the design process. It requires divergent thinking. To stimulate this kind of thinking students are asked to identify sub- problems and find several solutions for each sub-problem. The results are presented in a so-called “table for ideas”, which serves as a starting point for formulating a design proposal.

In their **design proposal** students have to take into account the list of requirements and the available materials and facilities at school. After approval by their teacher they elaborate the design proposal in a working prototype, examine to what extent the requirements are met and suggest improvements and modifications. It is not expected that students redesign their prototype. For reporting and process control a portfolio document is used.

3. Types of activities with a link to industry

We can distinguish different type of activities with a link to industry and tried to create a classification from low to high.

I. The context of the activity has a link, but the activity is rather traditional. In such an activity for example the application of science content in a certain product or process is demonstrated.

II. In the activity first an industry is studied, preferable by a site visit or studying or another good introduction, and challenges faced in that industry are used to introduce science activities. For instance ‘safety in cars’ lead to study the role of crushing zones, which will lead to related physics concepts.

III. Analysing an industries main product or process based on a site visit and study of both the science content and the design process/choices that have been made. Students should experience different solutions for the same design task.

IV. A design task given by the unit. Students will need to follow all steps in a design process. During the process they will need to learn science concepts and do experiments.

V. A design task with a customer. In this case contacts with industry leads to a design problem.

IV. LEARNING PATHS

Inquiry-based teaching and learning can be organized through an instructional learning model. The Learning Cycle is one of the most familiar and effective models for science instructions. Exemplary Learning Activities included in ESTABLISH Units offer activities with reference to the stages of the 5E model of Learning Cycle. Teachers as authors can structure their inquiry-based lessons by making their own selection of activities as useful for them in their particular teaching situation.

Units offer some exemplary ways of connecting Student Learning Activities to each other.

1. Learning cycle

The Learning cycle is one of the most familiar and effective models for science instruction. It was first introduced by Atkin and Karplus (1962) during the curriculum development movement of the 1960s (USA), and used in the Science Curriculum Improvement Study (SCIS). Initially the Learning cycle was proposed (Karplus, 1962) as a model of three phases, named Exploration, Invention, and Discovery, later renamed as Exploration, Development and Application, respectively.

In another model, Martin, Sexton, and Gerlovich (1999) have suggested 4Es - *Exploration*, *Explanation*, *Expansion*, and *Evaluation*. With the emphasis on constructivism and assessing prior knowledge, the *Engagement* phase has been added in a design study of BSCS (www.bscs.org), making the Learning Cycle a 5E model:

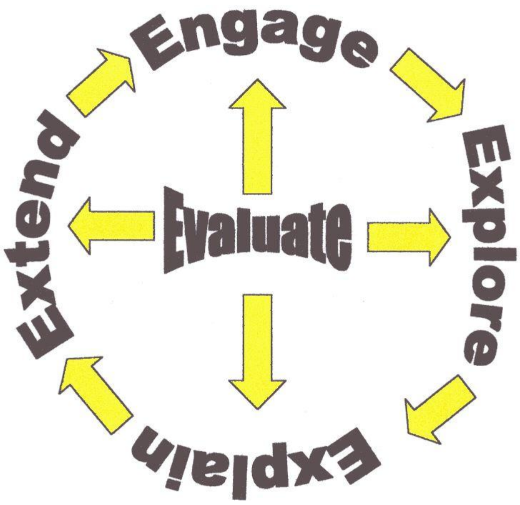

Figure 8. The 5E Learning model

1. **Engagement** – during this state, the teacher sets the stage for learning. The teacher wants to create interest and generate curiosity in the topic of study. This sets the stage for inquiring about a particular phenomenon. This phase also provide opportunity for the teacher activate learning, assess prior knowledge, and have students share their prior experience about the topic. During the Engagement state, the teacher can note students' current beliefs and understandings.

2. **Exploration** – this is an excellent time to engage students in inquiry. During this stage students raise questions, develop hypotheses to test and work without direct instructions from the teacher. They go about collecting evidence and data, recording and organizing information, sharing observations and working in cooperative groups. Following exploration, the teacher should have a period of reflection in which students discuss what was discovered and learned from exploration. (See also Inquiry-based investigations and Inquiry-based cycle).

3. **Explanation** – in this state the teacher facilitates data- and evidence-processing techniques for the individual groups or entire class (depending on the nature of investigation) from the information collected during the exploration. The information is discussed, and the teacher often explains scientific concepts associated with the exploration by providing a common language for the class to use. This helps students to think and describe their investigations and

experiences in scientific terms. Here the teacher uses the student's prior experience to explain the concepts and attempts to address misconceptions uncovered in the Engagement and Exploration stages (also called Concept development).

4. **Extend** (**Elaborate**) – during this state the teacher helps reinforce the concept by extending of applying the evidence to new situations. This stage also facilitates the construction of valid generalizations by the students, who may also modify their presently held understandings of the phenomenon being studied.

5. **Evaluate** – in this stage the teacher post higher-order questions that help students to make judgments, analyses, and evaluations of their work. This is also a moment for assessment of student understanding of concepts and skills.

The 5E Learning Cycle has turned to be a powerful and most popular instructional tool and lesson organizer for constructivist and inquiry-based science teachers. This is the preferred instructional model of inquiry teaching and learning for ESTABLISH project.

2. Which IBSE activities can be used at different stages of the Learning Cycle?

Below a list of IBSE activities for the five stages in the 5E model is given and of what students and teachers are expected to do. The list originates from the report *The BSCS 5E Instructional Model: Origins and Effectiveness* (2006; www.bscs.org).

Table 4: List of IBSE activities for each stage of the 5E model

Engage

The Student…	Explain Activities	The Teacher…
• Asks questions such as: • Why did this happen? • What do I already know about this? • What can I find out about this? • How can this problem be solved? • Shows interest in topic. • Responds to questions demonstrating their own entry point of understanding	Initiate the learning task. The activity should make connections between past and present learning experiences, and anticipate activities and organize students' thinking toward the learning outcomes of current activities. • Generate interest • Access prior knowledge • Connect to past knowledge • Set parameters of the focus • Frame the idea	• Raises questions and problems. • Elicits responses that uncover students' current knowledge about the concept/topic. • Generates interest. • Generates curiosity.

Explore

The Student…	Explain Activities	The Teacher…
• Thinks creatively within the limits of the activity. • Tries alternatives to solve a problem and discusses them with others. • Suspends judgment. • Conducts activities, predicts, and forms hypotheses or makes generalizations • Becomes a good listener • Shares ideas and suspends judgment • Records observations and/or generalizations • Discusses tentative alternatives	Provide students with a common base of experiences which current concepts, processes, and skills are identified and developed. • Experience key concepts • Discover new skills • Probe, inquire, and question experiences • Examine their thinking • Establish relationships and understanding	• Elicits responses that uncover students' current knowledge about the concept/topic. • Raises questions and problems. • Acts as a facilitator • Observes and listens to students as they interact • Asks good inquiry-oriented questions • Generates interest. • Generates curiosity.

Explain

The Student…	Explain Activities	The Teacher…
• Explains possible solutions or answers to other students. • Listens critically to other students' explanations. • Questions other students' explanations. • Listens to and tries to comprehend explanations offered by the teacher. • Refers to previous activities. • Uses recorded observations in explanations. • Uses previous observations and findings • Provides reasonable responses to questions	Focus students' attention on a particular aspect of their engagement and exploration experiences, and provide opportunities to demonstrate their conceptual understanding, process skills, or behaviors. This phase also provides opportunities for teachers to introduce a concept, process, or skill. • Connect prior knowledge and background to new discoveries • Communicate new understandings • Connect informal language to formal language	• Formally provides definitions, explanations, and new vocabulary. • Uses students' previous experiences as the basis for explaining concepts. • Encourages students to explain their observations and findings in their own words • Provides definitions, new words, and explanations • Listens and builds upon discussion form students • Asks for clarification and justification • Accepts all reasonable responses

Extend *(Elaborate)*

The Student…	Explain Activities	The Teacher…
• Applies new labels, definitions, explanations, and skills in new, but similar, situations. • Uses previous information to ask questions, propose solutions, make decisions, design experiments. • Draws reasonable conclusions from evidence. • Provides reasonable conclusions and solutions • Records observations, explanations, and solutions	Challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understanding, more information, and adequate skills. • Apply new learning to a new or similar situation • Extend and explain concept being explored • Communicate new understanding with formal language	• Expects students to use vocabulary, definitions, and explanations provided previously in new context. • Encourages students to apply the concepts and skills to new situations. • Reminds and refers students of alternative explanations. • Uses previously learned information as a vehicle to enhance additional learning • Encourages students to apply or extend the new concepts and skills • Encourages students to use terms and definitions previously acquired

Evaluate

The Student…	Explain Activities	The Teacher…
• Demonstrates an understanding or knowledge of concepts and skills • Answers open-ended questions by using observations, evidence, and previously accepted explanations. • Evaluates his or her own progress and knowledge. • Asks related questions that would encourage future investigations. • Provides reasonable responses and explanations to events or phenomena	Encourage students to assess their understanding and abilities and provide opportunities for teachers to evaluate student progress. • Demonstrate understanding of new concept by observation or open-ended response • Apply within problem situation • Show evidence of accomplishment	• Assesses students' knowledge and skills • Observes students as they apply new concepts and skills. • Looks for evidence that students have changed their thinking. • Allows students to assess their learning and group process skills. • Asks open-ended questions such as, Why do you think...? What evidence do you have? What do you know about the problem? How would you answer the question? • Encourages students to assess their own learning

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