FLEX-BASED LEARNING – A Program to Foster Scientific Creativity in Schools

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1. Introduction

In a world of increasing globalization and technological progress young people must learn to solve real problems for which there are no ready-made strategies to shape tomorrow's world in an innovative, resource-conserving, and sustainable way (Kind & Kind, 2007; Marope et al., 2017). Therefore, in many curricula, the so-called 21st Century Skills (Partnership for 21st Century Skills, 2015), which include for example creativity, critical thinking and problem-solving, are anchored.

Especially in the field of gifted education, the call to promote creativity is becoming louder and louder. Gifted students exhibit exceptional intellectual abilities as well as a high level of curiosity. Fostering their scientific creativity strengthens their ability to critically evaluate information, make connections between different concepts and develop novel approaches to challenges. This enables them to tackle complex problems with confidence and ingenuity.

To foster students´ creative problem-solving skills and to transform schools into innovative think tanks and maker spaces, a team of researchers and teachers at the University of Education Upper Austria, led by Kurt Haim and Wolfgang Aschauer, established the SCHOOL OF CREATIVE SOLUTIONS (SCS) as an international school network for creative problem-solving. For implementation in schools, SCS comprises two special learning and teaching programs – FLEX-BASED LEARNING (FBL) & INNOVATIVE FOCUS (InFOCUS) – including together a bundle of over 20 techniques.

The FBL program (Haim & Aschauer, 2022) was developed specifically for STEM subjects to promote aspects of scientific creativity like divergent thinking. Because this program does not only promote flexibility, in future the program will be called SCIP (Scientific Creativity in Practice).

The InFOCUS program was designed to foster students to challenge realistic problems. Therefore, this program trains students not only in different creativity techniques, but also in creative project management.

The SCS is intended to be a platform for all those who are firmly convinced that school can be much more than a place of pure knowledge transfer. School should be a place of creative work and problem solving. The visions of the SCS are:

- Students who face the challenges of the future with optimism and self-confidence.
- Teachers who can initiate innovative processes in the school.
- Schools who establish themselves as a think tank and maker space for the challenges in the context of the "Sustainable Development Goals".

2. Scientific Creativity

The concept of scientific creativity is significantly influenced by Guilford and Torrance and can be interpreted as a domain-specific creativity that includes both domain-specific and general creativity competencies (Hadzigeorgiou et al., 2012; Hu & Adey, 2002).

Tab. 1: Conceptualization of Scientific Creativity

Scientific Creativity	
Domain-Specific Competencies	**General-Creativity Competencies**
Generating Hypotheses	Divergent Thinking
Testing Hypotheses	Association & Bisociation
Problem solving	Imagination
etc.	etc.

Both parts are closely linked and mutually dependent on each other. For example, divergent thinking, (i.e., finding different solutions to a problem) succeeds most effectively if one also has the corresponding domain-specific knowledge and skills. Conversely, one can only discuss processes at the particle level without a certain degree of imagination. That means that when you promote scientific creativity, you also help the young people to build and strengthen their basic knowledge at the same time.

2.1 Domain-Specific Competencies

Creative work and ideas arise from the variation and recombination of existing knowledge elements in new patterns (Benedek & Fink, 2019). Therefore, knowledge of subject-specific concepts and their relationships as well as adequate skills, like the ability to formulate or test hypotheses are the basic prerequisites for creativity (Huang et al., 2017).

2.2 General-Creativity Competencies

General-creativity competencies include various cognitive skills such as divergent thinking, association and bisociation, analogical thinking, imagination, or metacognition (van de Kamp et al., 2015, Hadzigeorgiou et al., 2012; Hu & Adey, 2002; Kind & Kind, 2007).

Divergent Thinking

The American psychologist Paul Guilford (1956) first introduced the term divergent thinking as a counterpart to convergent thinking. For him, divergent thinking was one of the most essential prerequisites for creative achievements, because with divergent thinking it is possible to generate many original solutions.

Convergent thinking is important and helps us to classify and to categorize our world. Convergent thinking is fact-oriented and enables us to classify statements into right or wrong. We think convergently when our brain searches for a single correct solution.

In contrast to convergent thinking, divergent thinking is characterized by cognitive processes in which a problem is analysed from different perspectives (Kaufman et al., 2008). In this way, not only a solution is considered. It enables us to generate a wide variety of ideas. Especially in the context of scientific creativity, divergent thinking is therefore an important indicator of the creative problem-solving potential (Runco & Acar, 2012; Huang et al., 2017).

To measure the ability of divergent thinking it is common to distinguish between fluency, flexibility, and originality (Runco, 1999):

- Fluency - this refers to the total number of named ideas.
- Flexibility - this refers to the number of different categories to which the ideas can be assigned.
- Originality - this indicates how many of the named ideas are surprising and outside the expected range.

For creative achievements, the interplay of both ways of thinking, convergent as well as divergent, is crucial. Why is an interplay between convergent and divergent thinking so important for creative performance? The answer derives from the definition of creativity as the combination of different fields of knowledge into new patterns. For knowledge generation, convergent thinking plays a central role. Divergent thinking is necessary to link or recombine different content areas in a creative way.

Original Association and Bisociation

Original association refers to the combination of terms from a domain. In other words, the ability to recombine a wide variety of terms within a domain to form meaningful units. Bisociation is the linking of two very different and distant concepts and requires the skills of conceptual combination (Koestler, 1964; Ward et al., 1997). Both original associations and bisociations are elementary components of cognitive processes, and bisociation in particular is necessary as an essential factor for creative problem-solving (Benedek et al., 2020).

Analogical Thinking

Analogies aim at comparing different concepts and finding similarities between them. The ability to draw on a familiar analogous concept plays an important role in the student's learning process. Analogical thinking makes it possible to transfer the structure of an unfamiliar domain to a familiar content. Only by abstracting the essential features and considering the limits of abstraction a deeper understanding of a complex concept can be achieved (Arnold & Millar, 1996). In addition, the use of analogies in the classroom increases students' self-efficacy in learning new content as well as memorization in recalling features of a concept. Analogies are helpful in creative problem-solving because they allow similarities between two problems to be identified and proven strategies to be applied to the new problem (Condell et al., 2010).

Imagination and Fantasy

In psychological research, imagination or "seeing with the mind's eye" is a term with a broad definition (Kind & Kind, 2007). In general, it refers to the ability to mentally detach oneself from the current time, place, and circumstances. Only then is it possible to think about what might have been, to plan for the future, and to create fictional worlds (Taylor, 2011). According to this definition, imagination is not only the construction of images. The concept also includes the formation of internal ideas or scenarios. For both scientists and students, imagination is an essential prerequisite for scientific creativity and a necessary learning tool to access the world of atoms, molecules, field lines, and other scientific concepts (Hadzigeorgiou et al., 2012; Kind & Kind, 2007).

Metacognition and Personality Traits

Metacognition means to be able to reflect on one's own cognitive processes and actions on a meta-level and includes both knowledge elements and specific skills (Pacheco & Herrera, 2021). Especially in fostering learners' creativity in the classroom, metacognition has a clear positive impact (van de Kamp et al., 2015). In the context of scientific creativity metacognition includes for example:

- Knowledge of what characterizes divergent thinking.
- Knowledge about which thinking styles are necessary in the different problem-solving phases.
- Knowledge about what personality traits characterize creative people.
- Reflection on one's own performance in terms of fluency and flexibility of the generated ideas.
- Assessment of personal strengths and weaknesses in creative processes.

In addition to metacognition, various personality traits are also important for creative achievements, like curiosity, persistence, openness, and tolerance for failure (Feist, 2010; Kozbelt et al., 2010; Selby et al., 2005).

3. The FLEX-BASED LEARNING Program

Based on the concept of scientific creativity we designed the FBL program for STEM subjects. Scientific creativity comprises several creative skills and metacognition. Therefore, the FBL program not only includes different techniques for the individual creativity competences, but also three tools for metacognition (see Table 2).

Tab. 2: FBL techniques and their emphasis

Techniques	**Emphasis on Scientific Creativity**
Shorty & Flexy	Metacognition about fluency, flexibility & originality
Be a COMET!	Metacognition about own creative personality traits
Role Models	Metacognition about the own role in team processes
Thinkflex	Divergent thinking & metacognition
Flex-Experiments	Divergent thinking & metacognition
Clustering	Original association
WoSeCo	Original association
Live Act	Imagination, bisociation & metacognition
Visual Analogy Training	Analogical thinking, imagination & original association

The term *flex* stands for flexibility, one of the three important factors for divergent thinking, which is also particularly important for coping with real-world problems (Runco, 2004). Some of the FBL tools will be briefly described in the following sections. More information about FLEX-BASED LEARNING and the individual tools can be found in Haim & Aschauer (2022).

3.1 *Shorty & Flexy*

Shorty & Flexy are two imaginary figures supporting students to reflect and to analyse their ideas and thoughts.
In order to be able to discuss this metacognition element at students´ level, we use the brain as a library analogy with the books representing all our knowledge and experiences. And the thinking processes are represented by two imaginary actors called *Shorty & Flexy*.

Figure 1: *Shorty & Flexy* for metacognition about one´s thinking styles

Shorty can be characterised as:

- He is convenient and promptly provides you with obvious solutions.
- He provides a routine so that you can quickly make a decision.
- His ideas are tried and tested in everyday life, but not creative.

Therefore, Shorty is incredibly important to manage our daily life. With the help of his routine, we can generate solutions without much energy effort. However, Shorty stands for small-minded thinking and does not help us to develop original ideas.

Flexy can be characterised as:

- He gives you creative ideas.
- He needs a little longer for ideation.
- He loves to consider other perspectives, using the "perspective check".

Flexy stands for original thinking, who likes to take effort to break out of the expected frame. It helps us to break out of routine, to find original ideas. We therefore need it especially for brainstorming.

In order to be able to work effectively with Flexy during brainstorming, we have developed the Perspective Check for students (see Figure 2).

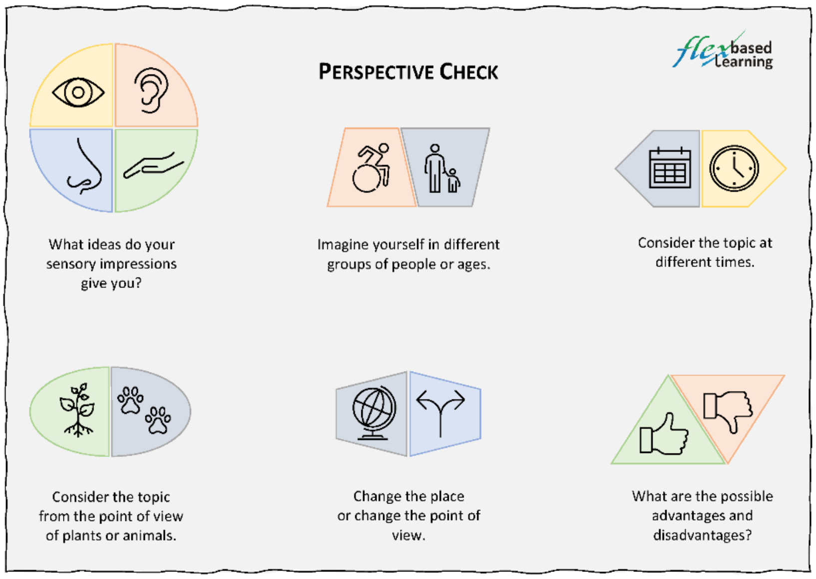

Figure 2: *Perspective Check*

The *Perspective Check* covers all the important thinking styles and guides the students from one perspective to another, asking them:

- What ideas do your sensory impressions give you?
- Put yourself in the shoes of different people or age groups.
- Look at the topic from the point of view of plants or animals.
- Change the place or change the point of view.
- What advantages and disadvantages can arise?

3.2 *Thinkflex*

Thinkflex is a tool to promote divergent thinking in the classroom. The name *Thinkflex* is derived from the two words think and flexibility. Therefore, *Thinkflex* is an invitation to the pupils to think flexibly, i.e. to expand their own way of thinking in all directions. The challenge in *Thinkflex* tasks is to generate as many and as different answers as possible. For this to succeed, the task should always be viewed from a wide variety of perspectives.

All *Thinkflex* tasks are linked to the contents of the curriculum of the respective subject and cover the typical subject-specific competencies. As an example, some thinking flex types for science subjects are given in table 3:

Tab. 3: Types of *Thinkflex*

Typ	**Example**
Asking questions	What questions can you think of about a candle flame?
Finding causes of errors	The table salt does not dissolve in water - Why?
Findings Possibilities	How can the humidity in the laboratory be increased?
Recognizing consequences & implications	What would be the consequences of a complete phase out of fossil fuels?
Recognizing advantages & disadvantages	What are the advantages and disadvantages of fireworks?
Finding Uses	What can you do with a robot that can jump 30 meters high?

Procedure of a Thinkflex

As with several other FBL techniques, a *Thinkflex* is done according to the Listen-Think-Pair-Share cycle (Lyman, 1981). This setting offers a perfect condition for creative work, as there is a balance between individual and group work. The students are encouraged to:

Listen – listen carefully to the task
Think – think about the task alone
Pair – discuss the individual answers in small groups
Share – share the results with the class

In a *Thinkflex*, the Listen-Think-Pair-Share cycle is realised as follows:

1. Task: Students are given a worksheet. This worksheet provides the tasks and guides the students through the different phases of the work. After the students have carefully read the problem statement, they should imagine the problem and possibly make a sketch of it. This step should primarily provoke students´ imagination.

2. Brainstorming: Now the students should come up with ideas regarding the task and note them on the worksheet. In order to be able to generate as many different ideas as possible, they are asked to work with the perspective check. This phase should last about 3 minutes. It is very important that students work individually in this first brainstorming phase because this way they are not influenced or disturbed by the ideas of other students.

3. Exchange: In this third phase the pupils present and discuss their ideas within the group. In addition, they also think about other possible answers within the group.

4. Presentation & Discussion: At the end, the students present their group results to the whole class. The teacher moderates and reflects together with the students the flexibility and originality of the answers using Shorty & Flexy. At the end, a joint collection of ideas should be created.

3.3 *Flexperiments*

The term *Flexperiments* stands for **flex**ible solution-orientated ex**periments**. In *Flexperiments* an open-ended task should be solved in many different ways. The main goals are:

- Fostering divergent thinking and action
- Promotion of Students´ fault tolerance
- Support students´ team competences
- Increase students´ self-efficacy in problem solving

- Breaking students´ functional fixedness

As with *Thinkflex* the tasks of *Flexperiments* are linked to the contents of the curriculum of the respective subject. The *Flexperiments* for science subjects can be divided into different types (see Table 4):

Tab. 4: Some Types of *Flexperiments*

Check hypotheses	Check sources of error
Separate substances	Synthesize substances
Implement possibilities	Identify features

The procedure of a *Flexperiment*

Flexperiments are usually carried out at the end of a subject area because students should have the necessary content knowledge and skills. According to Listen-Think-Pair-Share cycle, the procedure of *Flexperiments* is:

1. Task: Students are given a worksheet with the problem statement.

2. Brainstorming: First, the students brainstorm individually and note their ideas. In this “Brainstorming – unlimited” they can assume that they have enough time and any materials they want. In a second step, the students are informed that only certain materials are available for problem solving. Therefore, the “Brainstorming for implementation” starts, in which they individually think about ideas, considering the offered materials.

3. Exchange & Decision: In small groups the students exchange their ideas, and they decide which ideas they will implement.

4. Implementation: Now the students implement their ideas and note their results or observations.

5. Presentation & Discussion: Finally, all groups present their solutions in the class and discuss about difficulties that encountered and suggestions for improvement. Afterwards together a collection of creative solutions is created.

Remarks on Flexperiments

For implementation the students mainly can use everyday objects. The reason for this is that we want to promote the critical thinking style. Since many solutions are often only possible if the materials are misused by breaking the provided materials’ functional fixedness (Duncker, 1945). This is significant because functional fixedness often hinders problem-solving (Anderson, 2005).

For several reasons, it is important that students think of several different ways to solve the problem:

- The first solution is obvious and only requires convergent thinking.
- Divergent thinking is needed for more solutions.
- As the number of solutions increases, so does the originality.
- Every solution has advantages and disadvantages.
- They are prepared against failure. If a solution doesn't work, they have alternatives.

3.4 *Clustering & WoSeCo*

Clustering and *WoSeCo* are techniques that are used in the FBL program to support the development of adequate content knowledge on the one hand and to promote associative thinking as well as verbal fluency on the other.

Clustering
The main goals of *Clustering* are:

- Supporting students to structure the contents of a subject area.
- Promoting students to correctly interpret and assign technical terms.
- Preparing students to effectively cope other tasks like *WoSeco* or *Cluster Cocktail*.

Clustering can be used in the classroom in three different ways. To distinguish between the different forms, three distinct terms are used:

- *Structured Clustering*
- *Stormy Clustering*
- *Hurricane Cluster*

Structured Clustering
Students collect all the terms of a topic and record them written in the form of a cluster.

In figure 3 an example of *Structured Clustering* is presented. In the middle is the central term, in this case "AIR". Then, starting from the middle, other terms that come to mind are noted. Each term can become the starting point for another term.

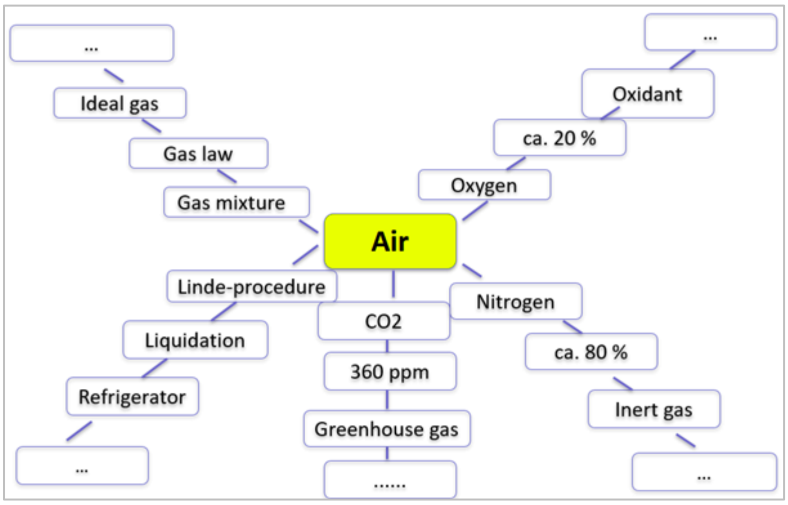

Fig. 3: Example of a *Structured Clustering*

A *Structured Clustering* can be done in different social forms. The students can do it by themselves or in groups. But it also possible that the teacher creates a *Structured Clustering* together with the whole class.

Stormy Clustering
A *Stormy Clustering* is one of the verbal forms of clustering. The students are asked to name as many words as possible in 2 minutes that come to mind intuitively for a particular topic.

1. The students line up in pairs.
2. The teacher sets the topic and limits the verbal clustering to a certain time (e.g., 2 minutes).
3. One student of each pair now names as many terms regarding to the given topic. This should be done as fluidly as possible without pauses
4. The counterpart counts all the terms mentioned.

Hurricane Cluster
A *Hurricane Cluster* is also a verbal form of clustering, and proceeds similarly to a *Stormy Clustering*. However, not only one student of each pair names terms, but both of them name terms, like in a ping-pong play.

WoSeCo
WoSeCo is an acronym that stands for word-sentence constructions. It is a tool for training original associations, which means linking terms from different chapters or topics of a subject.

The procedure of a *WoSeCo* is:

1. Two students sit or stand opposite each other.
2. The teacher gives a starting sentence with a technical term.
3. One of the students picks up the technical term and combines it with a new technical term to form a new correct sentence.
4. The partner now picks up the new technical term and combines it again with another technical term to form the next sentence.
5. These sentence formations are now continued alternately for as long as possible!

In the following an example of a *WoSeCo* form chemistry is presented. It begins with the technical word “METALS”. A brief explanation of the legend: The technical term to be built upon is always underlined and the added technical term is shown in bold.

- Metals are found on the left-hand side of the **periodic table.**
- The elements are ordered in the periodic table according to the **number of protons.**
- An element with the proton number 26 is **iron.**
- Iron can **oxidise** quickly.
- **Oxygen** is responsible for the oxidation.
- Etc.

The implementation in the class can be carried out in different variants. It can be done as a “single” *WoSeCo* with oneself, as a “partner” *WoSeCo* between two or more students, and between teacher and student. Thereby, the it can be performed as a written, verbal or digital *WoSeCo*.

4. Research Results about the Effectiveness of FBL

To investigate the effectiveness of the FBL program, we have conducted several studies since 2018 in which more than 2000 pupils participated. As a diagnostic tool the DPAS test (Aschauer et al., 2022) was used. DPAS stands for *Divergent Problem-Solving Ability in Science*. The term *divergent problem-solving* highlights that the focus of the test relies on the ideation phase, where different solutions should be found for a given problem.

In our intervention studies we use a two-group repeated measures design. So, the students are tested at the beginning and the end of the school year. In the control group, no specific techniques were used to promote divergent problem solving or SC. In the intervention group, teachers carried out several FBL interventions during the school year, on average about 10 interventions.

For operationalisation of creativity, we count the number of ideas for the fluency score and we count how many different categories are covered by these ideas for the flexibility score. Based on both scores the Creativity Quotient (CQ) was calculated as a composite creativity score including both, fluency and flexibility, but with more weight on flexibility (Snyder et al., 2004).

All our studies showed that the divergent problem-solving ability regarding to the CQ score significantly increases in the intervention group, whereas there is almost no change in the control group. As an example, the results of a study conducted in the schoolyear 2019/2020 are shown in figure 5. Detailed results of the study from 2018/2019 can be found in the publication of the validation of the DPAS test (Aschauer et al., 2022).

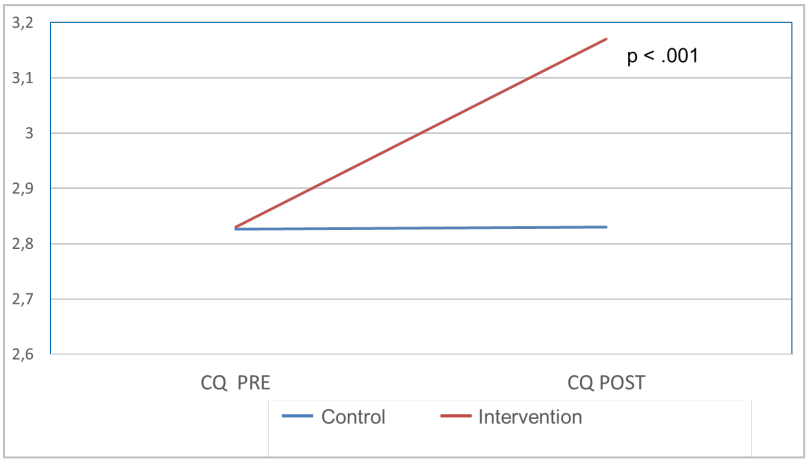

Figure 5: CQ scores at pre- and post-test in the control (n=283) and intervention (n = 287) group

The remarkable aspect is that this significant increase already occurs with an average of about 10 interventions. In order to implement the FBL program successfully, it is therefore not necessary to completely change the usual way of teaching. In our experience, it is sufficient if FBL techniques are used in about 20% of the teaching time.

5. FBL and its Contribution to the Education of Gifted Students

Several authors highlight the urgency of promoting scientific creativity, especially among gifted students (e.g., Cevher et al. 2014; Kizkapan & Nacaroğlu 2021; Kim, 2008; Stoltz et al., 2015). Above all, one reasons should be mentioned in this context. A high IQ alone does not provide a satisfactory explanation for highly gifted performance, but the interaction between intelligence and creativity must be considered (Cropley, 1993). Divergent thinking, originality, creative personality traits and a stimulating environment play a central role (Stoltz et al., 2015; Cropley, 1993), especially for gifted underachievers (Kim, 2008). Regarding to divergent thinking findings of Cevher et al. (2014) are evidence for the need to foster mainly gifted students´ originality (the ability to produce unusual or unique ideas) and elaboration (the ability to adapt abstract ideas into realistic solution).

Also, the research to explore the impact of FBL for educating gifted students is still ongoing, for several reasons we are convinced that our program can provide a great contribution in fostering gifted students:

- First results of our FBL intervention studies indicate that although gifted students had already higher CQ scores at the beginning, the FBL program nevertheless achieved a significant increase of the CQ. Thus, a saturation effect could not be detected.
- The program includes techniques that promote different aspects of creative thinking, strengthen creative personality traits, and consider the level of metacognition. In this way, both programs fulfill the call for a holistic approach in the support of gifted students (Cropley, 1993).
- Gifted pupils exhibit exceptional intellectual capabilities and possess a deep curiosity about the world around them. Fostering their scientific creativity and giving them the chance to solve real challenges, like in the InFOCUS program, we empower them to explore new horizons, we enable them to tackle complex problems with confidence and ingenuity, and we empower them to become future innovators.

More information about the FBL program and the related in-service teacher training courses, which are also offered for ERASMUS teachers, can be found at: https://www.school-creative-solutions.at/en/

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