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Fostering Scientific Creativity in the Classroom: The Concept of Flex-Based Learning

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Abstract. To sustainably shape tomorrow's world, young people must be prepared to develop successful solution strategies for problems that are as yet unknown. Therefore, it must be a core task of schools to train students in their problem-solving skills. The natural science subjects could become established to address this challenge if scientific creativity is explicitly promoted in the classroom. Therefore, the goal of a team of researchers and teachers was to develop a support program for scientific creativity. The developed program is summarized under the term Flex-Based Learning and includes a wide range of interventions linked to the most significant aspects of scientific creativity. The interventions have been developed and investigated since 2010 within a long-term design-based research project. The empirical inquiry, both in laboratory and real classroom settings, in which a total of 104 teachers and 3,516 Austrian secondary school students (aged 10–18 years) participated, indicates that Flex-Based Learning is efficient at the student level and is considered by teachers to be practical. In addition, the research also provided deeper insights into the conditions for fostering scientific creativity and the relationship between theory and practice.

Keywords: scientific creativity; divergent thinking; bisociation; metacognition; design-based research

1. Introduction

In a world of increasing technological progress, it is no longer enough to solve routine tasks; complex problems must be tackled (Autor et al., 2003). In this context, high-order skills, 21st-century skills, and creative problem-solving skills are key competencies to shape tomorrow's world in an innovative, resource-conserving, and sustainable way. For example, Sternberg (2010) and Ghassib (2010) highlight the importance of scientific knowledge and creativity. To prepare young people for tomorrow's world, creative and critical thinking must be taught in school (Silva Pacheco & Iturra Herrera, 2021). Students should learn to deal with new situations for which they do not already have a readymade strategy and

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handle problems creatively (Kind & Kind, 2007; Marope et al., 2017; OECD, 2014). As a result, creativity in science education and research on scientific creativity is becoming increasingly important. Scientific creativity can be interpreted as a kind of domain-specific creativity, including both domain-specific and general creativity competencies (Ayas & Sak, 2014; Barbot et al., 2016; Hadzigeorgiou et al., 2012; Hu & Adey, 2002; Huang & Wang, 2019; Sak & Ayas, 2013). Traditional science education in Austria focuses mainly on convergent thinking. Tasks or specific techniques that promote divergent thinking, creative problem solving, or other aspects of scientific creativity rarely occur. The reason for this can be given that teachers often do not know which skills are related to scientific creativity, and furthermore do not know techniques to train and promote these skills (Oyrer et al., 2020). Even in the literature, one can find only a few evaluated programs (Aktamis & Ergin, 2008; Siew & Ambo, 2018); Siew et al., 2017; Ayverdi & Aydin, 2018; Rasul et al., 2018; Hu et al., 2013; Yang et al., 2016) designed to foster scientific creativity. Moreover, these programs cover only one or two aspects of scientific creativity. To promote scientific creativity in secondary schools, the authors developed special teaching materials for science subjects in a long-term design-based research project, beginning in 2010. These novel teaching tools are summarized under the term Flex-Based Learning (FBL), covering a wide range of skills, all related to scientific creativity. In a development project lasting over 10 years, the FBL techniques were integrated into the subjects of biology, chemistry, and physics in a topic-specific manner, and worksheets were created for use in the classroom. This paper presents the theoretical framework of the FBL program, all FBL tools, and the main research findings.

2. Theoretical Framework

2.1. Scientific Creativity

Creativity is commonly defined as the ability to produce something novel or original as well as useful, effective, or appropriate (Barron, 1955; Runco & Jaeger, 2012; Stein, 1953). Therefore, it is obvious that the process of scientific research, in the sense of generating new theories or solving complex scientific problems, is closely related to creativity (Ayas & Sak, 2014; Feist, 2011; Heller, 2007; Hu et al., 2013; Hu & Adey, 2002; Lin et al., 2003). Therefore, various studies have investigated the conditions under which scientific research is highly innovative. For instance, some identified components include metaphors (Miller, 2000), analogies (Dunbar, 1994, 1999), intellectual achievement (Mumford et al., 2005), personality traits like openness and self-acceptance (Feist, 1998), and collaboration, as well as specific work strategies (Barrett et al., 2014). Even in science education, fostering scientific creativity in the classroom is becoming increasingly significant. One reason that should be highlighted in this context is, that young people must be prepared and trained to deal with new situations for which they do not possess a readymade strategy. Students should be able to think flexibly and creatively about overcoming various challenges and problems (DeHaan, 2009; Dikici et al., 2020; Kind & Kind, 2007; Marope et al., 2017; Mukhopadhyay & Sen, 2013; OECD, 2014).

The concept of scientific creativity is significantly influenced by Guilford (1956, 1967, 1968) and Torrance (1966, 2008) and can be interpreted as a kind of domain-specific creativity (see Figure 1), which includes both domain-specific and general creativity competencies (Ayas & Sak, 2014; Barbot et al., 2016; Hadzigeorgiou et al., 2012; Hu & Adey, 2002; Huang & Wang, 2019; Sak & Ayas, 2013). Regarding domain-specific skills, science-related activities, such as generating and testing hypotheses (Klahr, 2002; Klahr & Dunbar, 1988; Sternberg et al., 2020), problem-finding (Hu et al., 2010; Hu & Adey, 2002; Sternberg et al., 2020), and problem-solving (Hu & Adey, 2002) are mentioned in the literature. Regarding general creativity competencies, several cognitive creativity skills like creative thinking, especially divergent thinking (Ayas & Sak, 2014; Hu et al., 2010; Hu & Adey, 2002; Sak & Ayas, 2013), association and bisociation, metacognition (Lin et al., 2003; van de Kamp et al., 2015), and imagination (Hadzigeorgiou et al., 2012; Kind & Kind, 2007) are considered. For a detailed review of scientific creativity, see also Hadzigeorgiou et al. (2012), Kind and Kind (2007), and Mukhopadhyay and Sen (2013).

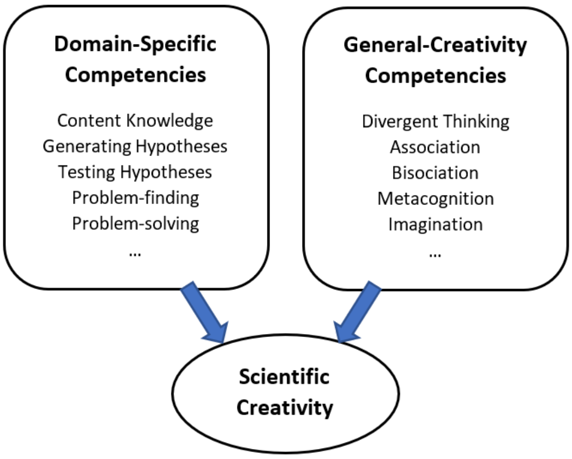

Figure 1: Conceptualization of Scientific Creativity

Importantly, the two components—domain-specific and general-creativity competencies—are closely related and mutually dependent regarding the formation of scientific creativity. For example, it is almost impossible to find different solutions for a problem—i.e., thinking divergently in the ideation phase—without the necessary corresponding scientific knowledge and skills. Conversely, it is difficult to think of processes at the particle level without a certain degree of imagination. Key aspects of scientific creativity, especially those related to general creativity, are outlined in more detail below.

2.2. Domain-Specific Competences

Creative ideas emerge the through variation and recombination of existing knowledge elements (Benedek & Fink, 2019), and thus, a solid conceptual framework is a prerequisite for fostering scientific creativity. Therefore, students should have a solid knowledge of scientific content to provide a foundation for creative thinking and action (Hadzigeorgiou et al., 2012). The development of content knowledge, which is seen as an essential aspect of creativity, is closely linked to convergent thinking, which allows existing knowledge to be processed and retrieved using standard procedures (Cropley, 2006).

In addition to content knowledge, other competencies primarily related to knowledge acquisition and problem-solving are important. According to the framework of scientific discovery as a dual search (Klahr, 2002; Klahr & Dunbar, 1988), knowledge acquisition and scientific research is based on searching for possible hypotheses and performing experiments.

Another key element is problem-solving (Hu & Adey, 2002), which can be interpreted as closing a gap between an initial state and a goal state. Other researchers have emphasized the initial stage, discovering the gap or so-called problem-finding (Hu et al., 2010; Sternberg et al., 2020). They consider problem-finding to be a key element in scientific research, about which Freeman Dyson has said the following: "It is characteristic of scientific life that it is easy when you have a problem to work on. The hard part is finding your problem" (as cited Csikszentmihalyi, 1997, p. 96).

2.3. General-Creativity Competences

Divergent Thinking

Divergent thinking occurs through cognitive processes that lead to various answers to a problem via switching perspectives (Kaufman et al., 2008). Three aspects are cited in the literature as necessary for the occurrence of divergent thinking: fluency, flexibility, and originality. Fluency is determined by the number of answers to a given problem, flexibility refers to considering different categories for ideation, and originality results from the uniqueness of a stated solution (Runco, 1999). Thus, divergent thinking leads to the generation of a wide variety of potential solutions when presented with a problem, which statistically increases the probability of successful problem-solving (Kaufman et al., 2008). Therefore, in the context of scientific creativity, divergent thinking represents a significant indicator of creative problem-solving potential (Runco & Acar, 2012). In a study by Huang et al. (2017), 15% of the variance in scientific creativity performance could be explained by divergent thinking.

Although divergent thinking contributes significantly to the performance of scientific creativity, the importance of convergent thinking should also be noted in this context (Agnoli et al., 2016; Cropley, 2006). Convergent thinking focuses on finding a prominent, often single correct and well-established answer to a question, leaving no space for ambiguity (Cropley, 2006). A study by Zhu et al. (2019) showed that convergent thinking acts as a kind of threshold setter. That is, divergent thinking becomes relevant only when convergent thinking reaches a certain level.

Original Association and Bisociation

In cognitive science, creative ideas are thought to arise from linking unrelated concepts, themes, or images (Mednick, 1962). Creative thinking is thus based on the fertile generation of original associations and bisociations. Original associations are distant associations within a concept and require the capacity for conceptual extension, whereas bisociations are associations between two very different concepts, requiring conceptual combination skills (Ward et al., 1997). Thus, bisociative abilities play an important role in linking knowledge and the ability to combine units into multiplicities (Silva Pacheco & Iturra Herrera, 2021). Hence, original associations, as well as bisociations, are considered elementary cognitive processes of creative cognition, with recent scientific literature including bisociation as an essential component of measuring creativity (Benedek et al., 2020). The term bisociation, which applies to all forms of creativity and was defined by Arthur Koestler (1964), thus represents a significant part of the creative process. Therefore, bisociative techniques are also central elements of many creativity techniques (SonicRim, 2001).

Analogical Thinking
Analogies aim to compare different concepts and find similarities between them. If inferences can be drawn about a familiar analogous concept, they can thus be drawn about less familiar concepts (Harré, 1972). The ability to form analogies plays a significant role in students' learning processes (Venville & Treagust, 1996). Using analogical thinking, the transfer of the structure of an unfamiliar domain to a familiar environment is possible. This mindset change, from focusing on "matter" to "processes," can also be facilitated. In addition, the use of analogies in the classroom increases students' self-efficacy in learning new content, as well as memory performance in recalling features of and interactions with a concept. A deep understanding of a complex concept can be gained by abstracting the essential characteristics and considering the limitations of the abstraction (Arnold & Millar, 1996).

Creating analogies to understand scientific phenomena and ideas has the potential to increase scientific creativity (Hadzigeorgiou et al., 2012). For example, analogies are helpful in problem-solving when the problem solver recognizes similarities between two problems and remembers how to solve one of them (Condell et al., 2010). Moreover, the use of analogies also helps scientists establish similarities between different domains, allowing them to use known ways of functioning in one domain to innovate in another. Many scientists and inventors have used analogies to achieve significant innovations. For example, James Dyson studied the action of a sawmill cyclone and applied its principle to a vacuum cleaner to increase the latter's effectiveness (Foreman & Drummond, 2008).

Metacognition
Effective thinking processes always require metacognition, as it requires significant planning, direction, and control of cognitive processes to optimize them. For example, especially in the context of creativity, it is necessary to know when, how, and why to use divergent thinking strategies. Therefore, several authors have emphasized the crucial role of metacognition in complex thinking (Silva Pacheco & Iturra Herrera, 2021), divergent thinking (van de Kamp et al., 2015), and scientific creativity (Lin et al., 2003) highlighting the significant positive effects of metacognition on fostering students' creativity in the classroom (Kaufman & Beghetto, 2013; Lin et al., 2003; van de Kamp et al., 2015). The conceptualization of metacognition comprises several components such as cognitive knowledge and cognitive regulation (Flavell, 1979).

Cognitive knowledge includes knowledge about oneself, the nature of a task and its requirements, and possible strategies (Flavell, 1979; Schraw et al., 2006; Silva

Pacheco & Iturra Herrera, 2021). In the context of scientific creativity, cognitive knowledge comprises the following examples:

- o Knowledge about what characterizes divergent thinking, especially in contrast to convergent thinking.
- o Knowledge about which thinking styles are preferred in different phases of problem-solving.
- o Knowledge about which personality traits characterize creative people.

Cognitive regulation summarizes the abilities to assess the process, the product, as well as the used strategy and covers the phases of planning, monitoring, and evaluation (Flavell, 1979; Schraw, 1998; Whitebread et al., 2009). Regarding scientific creativity, cognitive regulation contains the following components:

- o Reflections and assessment of one's own performance regarding fluency and flexibility of the generated ideas.
- o Assessment of the generated products.
- o Evaluation of personal strengths and weaknesses during the creative work in the team.

Imagination, Visualization, and Fantasy

In psychological research, imagination or "seeing with the mind's eye," is a term with a broad definition (Kind & Kind, 2007; Taylor, 2011). In general, it refers to a multi-faceted ability to mentally detach oneself from the current time, place, and circumstances in order 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 building up of images. The concept also includes the formation of internal ideas or scenarios (Pelaprat & Cole, 2011; Vygotsky, 2004). Therefore, imagination plays a central role in creativity because creative thinking requires the interplay of imagination and thinking (Magno, 2009; Smolucha & Smolucha, 1986).

The ability to imagine also plays a central role in the way scientists think and work. To understand the world, scientists need to visualize unobservable entities (e.g., atoms) and explain complex phenomena (e.g., electromagnetic induction) (Hadzigeorgiou et al., 2012). Thus, the ability to imagine is an essential element of scientific creativity (Holton, 1998; Holyoak & Thagard, 1996). Kind & Kind (2007) emphasize that imagination is essential for scientific creativity and a necessary learning tool to access the world of atoms, molecules, field lines, and other scientific entities.

3. Methodology

The aim of the research project was to develop different interventions, with each designed to promote specific competencies related to scientific creativity. Furthermore, deeper insight into the conditions and concrete framework for the effective promotion of scientific creativity was sought. The research project follows the design-based research approach (Barab & Squire, 2004; Design-Based Research Collective, 2003). In contrast to a pure formative evaluation study, where the focus is on optimizing a process or intervention, design-based research also develops or confirms theories. Thus, in addition to the developed products—e.g., specific interventions—research products are also created. Design-based research is interventionist, theory generative, reflective, iterative, ecologically valid, and practice oriented (Cobb et al., 2003; Prediger et al., 2015). Thus, it is very well suited for the purpose of this study.

Design-based research is characterized by a non-linear research process. Therefore, the development, optimization, and evaluation of each FBL intervention was conducted in several iterative cycles of design, investigation into design experiments, and re-design of the intervention based on the results of the design experiments. The following basic assumptions and considerations underpin the conceptualization of the FBL program, operating as design principles:

1. As scientific creativity includes a wide range of domain-specific and general creativity competencies, the FBL program should comprise a collection of diverse interventions.
2. FBL interventions should foster students' problem-solving abilities. Especially in real-world problem solving, flexibility is indispensable (Runco, 2004; Thurston & Runco, 1999). The FBL program should focus on promoting students' flexibility.
3. Current research should be considered when developing FBL techniques to promote all aspects of scientific creativity.
4. Since the promotion of creativity should always be accompanied by elements of metacognition (Lin et al., 2003; van de Kamp et al., 2015), the FBL program should also contain instruments for reflection on metacognition.
5. In team processes, students should work in a multiple-mode discussion cycle called Listen–Think–Pair–Share (Lyman, 1981).
6. Worksheets should be developed for all interventions so that teachers can implement the FBL program in the classroom without additional effort.

3.1. Instruments

After initial theory-based interventions developed in 2010 and 2011, iterative cycles of design-based research followed. Throughout this process, design experiments (Cobb et al., 2003) were conducted both in laboratory settings and in real classroom situations. At an initial stage, design experiments were accomplished in laboratory settings with a small group of participants to exclude interfering factors and focus on the intervention. Later cycles (see stage 2 and 3) were situated in classroom settings to explore the effectiveness and the practicability of the interventions (Prediger et al., 2015).

Stage 1:
The investigations carried out in the laboratory setting were conducted through micro-teaching sessions with student teachers in a student research lab at the University of Education Upper Austria from 2012 to 2014. In each micro-teaching session, two teacher students carried out one FBL intervention with three to four pupils. Semi-structured interviews and video analysis were used as instruments. The aim of these studies was to test the practicability and required conditions of the interventions, as well as their acceptance by the pupils and the effect of different settings on the interventions.

Stage 2:
From 2015 to 2017, teachers who are part of the research team tested the interventions in some of their classes. Semi-structured interviews, video analyses, and questionnaires were applied as instruments.

Stage 3:
To implement the FBL program in science classrooms, a one-year teacher training program has been offered since 2018. During the program, teachers receive insights into the theoretical aspects of scientific creativity and are introduced to the individual FBL techniques and their concrete applications in the classroom. The teacher training program provides an opportunity for further development and optimization of the interventions and the evaluation of FBL at both the student and teacher levels.

Student level: To investigate the effectiveness of the FBL teaching concept at the student level, the authors developed a divergent problem-solving ability in science (DPAS) test (Aschauer et al., 2021). Divergent problem-solving ability refers to the trial's focus—namely, the assessment of students' potential to design different possible solutions to address a particular scientific problem. To evaluate FBL, DPAS tests have been used in several pilot studies (e.g. Haim & Weber, 2014), as well as in the validation study of the DPAS test (Aschauer et al., 2021). The studies were conducted in a two-group repeated measures design. The test was administered both at the beginning and end of the school year. In the intervention classes, the teachers who participated in the teacher training program implemented the diverse FBL tools continuously throughout one school year. In contrast, no specific interventions were implemented to promote scientific creativity in the control classes, which were primarily taught by the same teachers.

Teacher level: At the teacher level, semi-structured interviews were used, in which the teachers reflected on their experiences implementing FBL techniques in their classes, to investigate the practicality and necessary conditions of the intervention. In addition, a questionnaire was developed (Oyrer et al., 2020) to examine the effectiveness of the course at different levels of impact (Kirkpatrick & Kirkpatrick, 2006).

3.2. Sample

At the various stages and levels, a total of 104 teachers, 24 student teachers, and 3,516 Austrian secondary school students (aged 10–18 years) participated in the investigations. Table 1 provides an overview of the sample at each stage.

Table 1: Overview of the participants in the investigations at the various stages

Stage	Students 5th to 8th grade ages 10 to 14	Students 9th to 12th grade ages 15 to 18	Student Teachers	Teachers
1	60 (46% male)	0	24	0
2	149 (49% male)	76 (30% male)	0	4
3	2,248 (48% male)	983 (43% male)	0	100

4. Flex-Based Learning Interventions as a Design Product

All interventions are summarized under the term flex-based learning. "Flex" is used here as an abbreviation of "flexibility" for simplicity, since the focus of this program is on promoting cognitive and experimental flexibility. In this context, flexibility is defined as a person's ability to adopt a variety of perspectives on a given topic, as well as the ability to implement a wide variety of solution strategies in scientific problems, including experimentally. Therefore, the FBL program focuses on promoting flexibility in divergent, critical, associative, and analogical thinking, as well as in imagination, metacognition, and experimental problem-solving skills.

In many FBL techniques, students work in a multiple-mode discussion cycle called Listen–Think–Pair–Share (Lyman, 1981). This setting creates ideal conditions for creative work because there is a balance between individual and group work. Specifically, in this cycle, students are trained to 1) listen carefully to the task ("listen"); 2) think about it alone ("think"); 3) discuss their answers in small groups ("pair"); and finally, 4) share the results with the whole class ("share").

The processes of our design-based research resulted in seven interventions and three reflection instruments. Of the seven interventions, five were completely newly developed (see Table 2*). Two interventions—mind mapping and memorization—were adapted for this approach. Finally, three instruments for reflecting on thinking strategies, team competence, and personality were generated (see Table 2**). The up-to-date versions of all interventions are now presented below.

Table 2: Summary of all FBL interventions and reflection tools
(* Self-developed FBL techniques ** Survey instruments for metacognition)

Thinkflex*	Flex Experiments*	WoSeCo*	Nano Live Act*	Visual Analogy Training*
Memorization	Mind mapping	Shorty, Mitty & Flexy**	Role Models**	Be a COMET!**

4.1. Thinkflex

The term Thinkflex covers cognitive thinking tasks that aim to increase mental flexibility by consciously changing perspectives. The name Thinkflex asks students to think flexibly to work through problems. A key element of all Thinkflex tasks is the developed Perspective Check. This tool helps students think divergently in different categories by guiding them step by step from one thinking perspective to another. The section is a word–picture guide. As students work through a Thinkflex task, they are asked to imagine what a problem might look like, what impact the problem would have on people, animals, and plants, what advantages and disadvantages the problem would present, and so on (see Appendix 1).

To reflect on both the thinking processes and the ideas themselves at the end of the task, the reflection tool Shorty, Mitty & Flexy is used. It serves to promote students' metacognition about their own thinking strategies by evaluating whether the self-generated idea was obvious or whether they broke out of the thought expectation. Three imaginary actors are used for this purpose, which will be described in more detail later.

All of the Thinkflex tasks are linked to the traditional topics of the respective subject and relate to young people's everyday world and experiences. The tasks target typical scientific thinking, which trains students in various action dimensions of scientific competencies. The following table (Table 3) provides an overview of some of these action dimensions.

Table 3: The most common types of Thinkflex tasks

Recognizing consequences & implications	Identifying opportunities & risks	Recognizing advantages & disadvantages
Forming hypotheses	Finding arguments	Finding uses
Finding reasons	Finding causes of errors	Describing possibilities
Asking questions	Identifying distinctions	Drawing conclusions

The following is an example of the Thinkflex type "Advantages and Disadvantages" from the following chemistry subject: "List as many advantages and disadvantages of fireworks as possible. At the end, assign all your answers to specific categories and also think of alternatives to fireworks." The worksheet for this Thinkflex task, including a Perspective Check, is included in Appendix 1.

Description of the Procedure. In the Thinkflex tasks, students work according to the Listen–Think–Pair–Share method described above (Lyman, 1981). For this purpose, worksheets have been developed for all Thinkflex tasks, which guide the student from one work phase to the next. Specifically, these phases are named and briefly described as follows (see Figure 2):

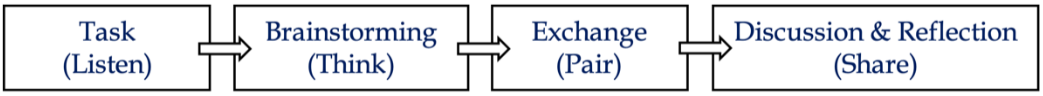

Figure 2: Four work phases in a Thinkflex task

1. Task: First, the teacher introduces the task to the students. Then each student sketches the problem on their worksheet.
2. Brainstorming: Each student first works out as many different solutions as possible using the Perspective Check. The ideas are entered onto the worksheet.
3. Exchange: The students now exchange their ideas in teams of three to five people and think about other possible answers within the group.
4. Discussion & Reflection: At the end, the student teams present their ideas to the whole class. The teacher reflects together with the students on the originality of the answers using the tool Shorty, Mitty & Flexy and creates a category system into which the solutions mentioned are assigned (see later).

Thinkflex Tasks in the Context of Scientific Creativity
Divergent thinking plays a central role in the context of scientific creativity (Runco & Agar, 2012). The Perspective Check of the Thinkflex tasks has proven to be an ideal promotional tool to promote this kind of divergent thinking. This guided change of perspective makes it easier for adolescents to adopt various viewpoints (flexibility) and thereby generate a variety of responses (fluency). This also allows for the inclusion of ideas outside the expected horizon, increasing originality. Bisociation is trained primarily in Thinkflex tasks of the type "Uses" by often bringing together two concepts that do not belong together in the first place (e.g., "A gardener gets a truck full of Erlenmeyer flasks delivered. What can he do with it to get some benefit?").

Imagination and visualization are required at the beginning of each Thinkflex task, as young people are supposed to imagine the task with all their senses and record the thought images in a sketch. This step requires a high level of imagination and is essential for effective ideation.

Metacognition regarding thinking strategies can be achieved on two levels. Through the pre-determined work phases, each student in the exchange phase recognizes how successful they were in solo-brainstorming or what perspectives they overlooked. On the other hand, through the reflection tool Shorty, Mitty & Flexy, all ideas are reflected and categorized in terms of their genesis in the brain.

4.2. Flex Experiment
Flex Experiments are a particular form of problem-solving experiment. The starting point is a realistic and subjectively significant problem formulated to stimulate cognition and enable independent action. The challenge is such that the students should not solve the problem only once but find as many different solution variants as possible and implement them experimentally. The students can choose from a predefined selection of materials, primarily everyday materials, to succeed. To make it easier for teachers to purchase or coordinate these materials, a so-called "flexbox" has been developed, containing all the materials for all flex Experiments for a given class size.

The problems were selected to relate to the most common topics in chemistry, physics, and biology lessons to ensure that flex Experiments can be integrated into any science lesson. The flex Experiments can be divided, for example, into the following types (see Table 4):

Table 4: Types of flex Experiments

Check hypotheses	Check sources of error	Conduct analyses
Construct structures	Synthesize substances	Separate substances
Build models	Implement possibilities	Identify features

The following are examples from chemistry and physics: "*Find as many ways as possible to make a candle flame go out using only gases*" and "*Find as many ideas as possible to distinguish saltwater from freshwater.*" In Appendix 2, both tasks are detailed.

Description of the Procedure

Again, students work according to Lyman's (1981) Listen–Think–Pair–Share setting. Worksheets were developed for all flex Experiments to guide the youth from one phase to the next. The phases are briefly described below (Figure 3).

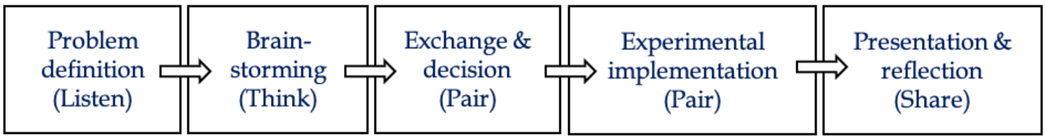

Figure 3: Five work phases in Flex Experiments

1. Problem definition: Flex Experiments start with an attractive problem definition, which should be relevant to and, above all, motivating for the students.
2. Brainstorming: Each student first thinks alone about possible solutions. The goal is to generate many different ideas and write them down or sketch them on the worksheet.
3. Exchange & Deciding: Students share their ideas in teams of three to five and decide which ideas to implement and how. They independently plan their approach and sketch possible experimental setups.
4. Experimental Implementation: The student teams work entirely independently. They implement as many ideas as possible with the given materials and re-record their results on the worksheet.
5. Presentation & Reflection: At the end, the student teams present their implementations to each other. Under the teacher's guidance, the groups reflect on their results and possible unsuccessful approaches.

Flex Experiments in the Context of Scientific Creativity

The unique feature of Flex Experiments is the demand for multiple solution implementations. Divergent thinking is explicitly trained through searching for and implementing as many different solution ideas as possible. Finding many ideas (fluency) can succeed in changing perspectives (flexibility), and as the number of solution ideas increases, so does the probability of unorthodox problem solutions and thus the originality of the solution approaches. Through these multiple-solution approaches, young people are provoked to leave their typical thinking routine to follow apparent solution approaches.

However, many solution ideas are only possible in most cases by breaking the provided materials' functional fixedness (Duncker, 1945). This is significant because functional fixedness, the inability to perceive new relationships or uses for objects, inhibits problem-solving (Anderson, 2005). Thus, young people must find ways to misappropriate the materials in flex Experiments. Thus, by seeking alternative uses, the bisociation that is so important to creativity is fostered.

In flex Experiments, however, the young people are also challenged in their imagination and ability to visualize by being asked to record their ideas or plans in sketches before the experimental implementation. Flex Experiments provide opportunities for metacognition on the following three levels: thinking process, team process, and self-efficacy.

The Listen–Think–Pair–Share setting succeeds in reflecting the thinking process in two aspects. Through individual work during brainstorming, each student remains uninfluenced by the ideas of the others. It is not until the group phase that the student becomes aware of how effective they were in brainstorming compared to the others and what thinking strategies their peers used. In addition, at the end of each flex Experiment, all solution attempts are compared in front of the entire class. The different implementations are categorized, the different experimental approaches used by each group are discussed, and failed attempts are reflected upon. Thus, in turn, the thinking patterns of the respective teams are contrasted and compared.

The self-reflection of the team process succeeds through the use of the reflection sheet entitled Role Models. With this tool, the role behaviors during the experimental phase are surveyed and discussed in terms of self-perception and external perception. This tool is especially recommended in cases of insufficient team competence, which is discussed in more detail below.

The authors have developed the reflection tool Be a COMET for the metacognition of one's own personality traits. After completing a flex Experiment, the Be a COMET tool reflects the typical personality traits necessary for creative challenges. Particular attention is given to promoting positive attributional patterns, such as the controllability and effortfulness dimensions. This tool is also presented in more detail below.

Especially in flex Experiments where students have to follow unknown paths, the probability of failure must be considered. Therefore, to promote a positive error culture, a unique setting was chosen for the experiments that considers the concept of "Productive Failure" by Manu Kapur (2008). According to this idea, three conditions are essential for developing a positive failure culture. On the one hand, problems should be chosen that are challenging but manageable (1). Furthermore, the learners should have the opportunity to explain or describe failed processes in a reflection phase (2). And finally, the teachers should be able to compare and contrast good and suboptimal solutions (3). And all these 3 conditions are guaranteed in flex experiments. These three frameworks take away the students' fear of failure, encouraging them to pursue unconventional, unpredictable paths. The real-life implementation of creative ideas plays a central role in building solid and lasting problem-solving skills (Thurston & Runco, 1999), and flex Experiments can help fulfill precisely this requirement. Although flex Experiments usually last only one to two teaching units, they contain the necessary processes of "idea generation," "idea selection," "implementation," and "presentation" that a larger-scale real-world project would also involve.

4.3. WoSeCo

WoSeCo is an acronym for word–sentence constructions. In WoSeCo, young people are encouraged in their linguistic competence by generating original associations between technical terms. In this way, students are tasked with combining technical terms acquired in class with technically correct sentences in a new context. The goal is to properly use subject vocabulary and link two words from distant topics within the subject. Such distance from the content thus trains the students to "think outside the box."

Description of the Process Based on a Concrete Example

When performing a WoSeCo, usually two students interact with each other. After the teacher has provided a sentence containing a familiar technical word, the students proceed as follows: one student picks up this technical word and combines it with any other technical term to create a meaningful and technically correct sentence. After a second student has recognized the added a technical term, they pick it up and combine it again with another new technical word. This procedure is repeated until the students can no longer think of new sentence constructions. As a rule, a WoSeCo lasts between one and three minutes.

The following is an example wherein the technical term to be built upon is underlined, and the added technical term is shown in bold:

There are about 80 ***metals*** *on our planet.* <u>*Metals*</u> *can be found on the left side of the* ***periodic table.*** *The elements are arranged according to the* ***proton number*** *in the* <u>*periodic table*</u>*. An element with the* <u>*proton number*</u> *26 is* ***iron****.* <u>*Iron*</u> *can* ***oxidize*** *quickly.* ***Oxygen*** *is responsible for* <u>*oxidation*</u>*.*

WoSeCo in the Context of Scientific Creativity

A solid technical vocabulary is an essential prerequisite for a WoSeCo. The student must recall the technical terms and know their technical meanings. Therefore, this technique is used to practice and consolidate the correct application of technical knowledge.

However, the main goal of WoSeCo tasks is to encourage the construction of original associations. Thus, this intervention challenges the student to form associations between subject terms within a subject. Depending on which combination of terms the student is capable of, the quality of the adolescent's intellectual originality can be inferred. Thus, low originality is shown when subject terms are used in chronological order according to the course of the lesson. The more the student can make significant thematic leaps, the greater their potential for highly original thought constructions. The following example with the term sulfur shows a very original association: "Sulfur has the element symbol S. S is also used as a symbol for entropy."

4.4. Nano Live Act

In a Nano Live Act, young people present the microcosm of a scientific phenomenon or experiment through live animation. For this, the students "slip into" the role of the smallest particles and provide a view into the nanoworld using their bodies and selected utensils such as ribbons, cloths, balls, etc. In the Nano Live Act, the pupils have to change their perspective from the macrocosm to the microcosm and back again.

Description of the Procedure

Each Nano Live Act relates to a science experiment along with a specific aspect to be demonstrated. Ten to twelve students form a group, nominate a speaker to comment on the performance, and an interpreter to bring individual excerpts of the Nano Live Act back into scientific presentation form using formulas and equations. Selected materials are provided to the students for the performance. The entire course of a Nano Live Act lasts about 45 minutes and can be divided into four phases (see Figure 4).

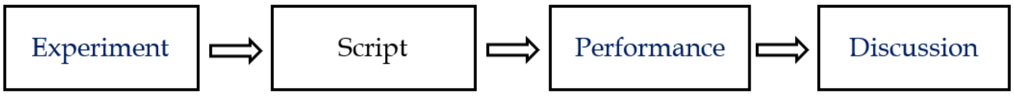

Figure 4: Four work phases in Nano Live Acts

1. Experiment: Students conduct a science experiment in small groups of two to four people. These experiments are usually simple in nature, often requiring little time.
2. Script: Several small groups form a large group of 10–12 participants and then think about a script for the task. In doing so, they rehearse the sequence of the action.
3. Performance: While one large group presents its performance, the others act as an attentive and critical audience.
4. Discussion: With the whole class, the teacher discusses the scientific correctness and the originality of the performances.

The following are two Nano Live Act examples: “Using a Nano Live Act, demonstrate the phenomenon of flame coloration” and “Using a Nano Live Act, demonstrate the influence of the surface area and temperature on the rate of chemical reactions.”

Nano Live Act in the Context of Scientific Creativity

Scientific phenomena and content can be better understood when students actively reenact an analogy (Ashmann, 2009). Kinesthetic analogies involving concrete objects or actions facilitate the understanding of particularly abstract scientific processes. Asking students to develop and demonstrate kinesthetic metaphors for science topics leads learners to think deeply about the concepts (Rule & Olsen, 2016).

To complete the task outlined above using Nano Live Act, students must immerse themselves in the microcosmic world. Thus, this intervention specifically trains the imagination, as well as the ability to visualize. Both aspects are necessary for young people to translate their body performance into the language of scientific formulas. This change from a performance to a scientific language is essential for the comprehension of scientific phenomena. In this way, it is possible to transfer observations and results of scientific phenomena to an abstract mental particle level. In this way, students acquire the competence to form hypotheses and interpret the results of scientific experiments.

Due to this open form of teaching in a Nano Live Act, effective interaction among the students within a group is important. To bring team competence to the required level for this, the authors recommend looking at the metacognition of the team process. For this purpose, employing the reflection tool Role Models again proves useful.

4.5. Visual Analogy Training

Visual Analogy Training is a tool in which students are asked to find analogies between taught content and everyday objects or phenomena. For this purpose, students are presented with images that exhibit similarities to specific properties or functions of scientific content. The goal is also to locate the boundaries between the learning content and the analog examples. Through Visual Analogy Training, students first learn to find analogies to generate bionic solutions to scientific problems.

Implementation

Before the Visual Analogy Training, the content-related discussion of a given topic should have already taken place in the class. This means that concrete properties, functions, principles, and characteristics of a specific subject have been discussed. The students are given a worksheet with several pictures from everyday life. On the one hand, the task now is to find similarities or connections between the subject content and the everyday examples. On the other hand, the aim is to point out aspects where the analogy does not match the initial scientific topic. Visual Analogy Training also works in a List–Think–Pair–Share setting. Visual Analogy Training can be practiced at different levels of difficulty by asking young people to work only with the images provided or even by suggesting their own pictures.

Visual Analogy Training in the Context of Scientific Creativity

Analogies can enhance scientific creativity (Hadzigeorgiou et al., 2012) by transferring a problem-solving strategy from a known problem to a new one (Condell et al., 2010) or using known ways of functioning from one domain in another (Foreman & Drummond, 2008).

Visual Analogy Training does an excellent job of promoting the ability to form analogies and thus bisociation, as similarities between two completely different ideas or concepts must be established. Therefore, analogies provide an opportunity to introduce the topic of bionics in the classroom. Bionics, a synthesized word between biology and technology, involves transferring natural phenomena to technology. As an interdisciplinary field of research, bionics plays a vital role in developing innovative products.

However, Visual Analogy Training is also ideal for generating "strange" images. These are of great importance in the creation of mind maps but also for the generation of mnemonic stories, as discussed below.

In the FBL program, analogies are explicitly used with complex topics for cognitive understanding. Thus, Visual Analogy Training facilitates the understanding of complex content and, subsequently, the storage of content knowledge. Since scientific knowledge is considered a prerequisite for creative thinking (Hadzigeorgiou et al., 2012), analogies also contribute to increasing scientific creativity in this respect.

4.6. Memo Tools

Memo Tools represents a collection of memorization techniques that were selected by the authors from the known literature to effectively memorize natural science data. The integration of these techniques into the FBL program has two goals. On the one hand, the students are taught a learning technique that makes it easier to store basic knowledge in their long-term memory. Second, memorization techniques provide an ideal opportunity to foster imagination in the context of science topics.

Memorization techniques are based on the mental visualization of information in imaginative images. This approach is used in well-known memorization techniques such as Keyword–Method, Memo–Story method, and Number–Story–System. All methods have in common that the inner pictures should be imagined in a colorful, moving, and exaggerated way for successful mental visualization.

Description of a Concrete Example

An example of the keyword and number–shape methods preferably used for memorizing numbers is presented here. First, the numbers 1 to 10 are symbolized by objects with shapes similar to the numbers—for example, the number 3 could be represented by an opened handcuff. These symbols are combined with the information to be remembered to form a memory picture. As a concrete example, if it is to be memorized that the third main group of the periodic table of the elements begins with the element boron, using the keyword method first, the term "boron" is converted into the imaginable and similarly written word "boring rig." Finally, the keyword "boring rig" is linked using the imaginative picture with the symbol for 3, i.e., a handcuff.

Memorization in the Context of Scientific Creativity

Since the availability of specialized knowledge (content knowledge) is considered an essential prerequisite for creative ideas, the sustained memorization of basic knowledge represents a vital role in fostering scientific creativity (Hadzigeorgiou et al., 2012). Memorization techniques, therefore, make a valuable contribution to making scientific creativity possible.

Further benefits can be obtained from memorization techniques if the students themselves generate them. Thus, each self-generated memorization story also provides feedback on its originality. The more original a memo story is, the more sustainably it can be stored in the memory. At the same time, memorization techniques also encourage imagination and fantasy in science subjects, making memo aids another contribution to the promotion of scientific creativity.

As in the number–shape method example presented above, a link is made between two alien concepts such as "boring" and "rig." This is an impressive example of bisociation, one of the most significant factors in promoting creative problem-solving skills.

4.7. Shorty, Mitty & Flexy

Shorty, Mitty & Flexy is a reflection tool for metacognition regarding thinking strategies. To reflect on their thinking strategies in the brainstorming process of the Thinkflex tasks and the flex Experiments, students are asked to analyze their generated ideas in the respective reflection phase. Here, the assessment tool Shorty, Mitty & Flexy has proven helpful in that the young people assign their ideas to three imaginary actors who are held responsible for the ideas coming up in their brains. Shorty represents our small-minded thinking, which develops obvious ideas with little cognitive effort. Shorty ideas are the first to come to mind and are also the most frequently mentioned. Mitty provides us with ideas that require a little more cognitive effort but can still be counted as average ideas. Flexy represents original thinking that spares no effort to break out of the expected realm. Flexy thoughts occur when unusual perspectives are taken that no one expected. Although flexy ideas may come to mind spontaneously, the perspective check mentioned above can help students break through the expectation zone and generate original ideas.

To show students the entire perspective spectrum of a problem, all ideas are also categorized according to their characteristics at the end of the reflection phase. For this purpose, the students and the teacher look for similarities between their Thinkflex ideas or implemented experiments.

Implementation

For metacognition regarding the thinking process, a poster with imaginary actors was developed by the authors. In addition to the pictorial representation of Shorty, Mitty & Flexy, this poster also describes their typical characteristics. The poster is hung up in the classroom so that the three thinking strategies are always present and an assignment based on the ideas can be done quickly and at any time.

Shorty in the Context of Scientific Creativity

The moment young people reflect on how and with what effort an idea may have been formed in the brain, they can control their thinking. Whether the mappings are correct, thinking about one's thinking is key to increasing flexibility and fluency (van de Kamp et al., 2015).

In addition, finding similarities of all the ideas produced is a valuable contribution to metacognition of the thinking process. The categories thus formed provide feedback to the students regarding their thinking flexibility, as it becomes clear which perspectives have been pursued and which have been overlooked. Here, the unique role of the perspective check should be mentioned once again, with the help of how the adopted way of thinking can be consciously changed or controlled. In this way, students are repeatedly shown that they can generate original ideas by observing and engaging with their thinking process.

4.8. Role Models

Role Models is a reflection tool for metacognition of teamwork skills. It facilitates self-reflection on role behavior in team activities. Typical role behaviors frequently observed in creative processes are depicted with the help of exaggerated characters. Roles such as The Idea Bringer, The Dominant Leader, The Social Leader, The Practitioner, The Fence-Sitter, and The Lazy One are used.

Implementation
This reflection tool is often used in flex Experiments as well as in Nano-Live Acts, as the open form of teaching can lead to social tensions within the groups. After all, young people often have to make difficult decisions—for example, which ideas are to be selected for experimental implementation and how they are to be realized in concrete terms.

The reflection sheet on role behavior is thus used after completing the respective techniques. Using worksheets, the students assign themselves to the characters listed above. Afterward, they exchange their reflection sheets and discuss self-perceptions and perceptions of others in the group. Later, the teacher can present best-practice examples of successful teamwork and reflect on them together with the students.

Role Models in the Context of Scientific Creativity
In a team process characterized both by an open form of teaching and by the many degrees of freedom in implementation possibilities, effective team interaction is of crucial importance. Therefore, it is essential to make conflicts that have arisen immediately visible and point out concrete strategies for addressing them. The use of the reflection sheet provides a reasonable basis for this, as the team process is examined in terms of self-perceptions and external perceptions.

4.9. Be a COMET
The capacity for creative work is also essentially determined by personality (Barron, 1995; Feist, 2010; Kozbelt et al., 2010). Therefore, a reflection instrument for significant personality traits was developed by the authors, including a reflection sheet. Be a COMET presents the most influential personality traits as compared to a comet. COMET is an acronym for the following attributes: "c": courageous; "o": open for new things; "m": mindful; "e": enduring; and "t": tolerance for mistakes. The analogy with the celestial object was chosen because, as with a comet that recurrently "comes out of nowhere" and attracts attention by glowing, it is also up to the creative person to retreat at certain stages of the creative process to reflect on the problem to help their creative ideas break through after brainstorming and put these ideas in the spotlight.

In creating the reflection sheet, the concept of "fixed and growth mindsets" by Dweck (1999, 2015) was explicitly integrated for the metacognition of self-efficacy and reflection on fault tolerance.

Implementation
In the first step, teachers introduce the topic of creative personality to their students using the reflection tool "Be a COMET." Afterward, the students are asked to reflect on their personality profile and mindset using a reflection sheet. The results of this survey are discussed together with the teacher to strengthen positive attribution patterns and build up a positive culture of mistakes. Teachers are advised to integrate personality metacognition into their lessons on a regular

and situational basis. Especially in flex Experiments and in Nano Live Acts, self-efficacy and fault tolerance should be addressed.

Be a COMET in the Context of Scientific Creativity

Creative action requires the complex interaction of various personality traits (Barron, 1995; Feist, 2010; Kozbelt et al., 2010). Especially in creative processes where habitual thinking patterns have to be left behind and failure has to be expected, it is essential to assess one's strengths and weaknesses. This enables adolescents to recognize how their personality traits influence their self-confidence and, thus, their performance (Silva Pacheco & Iturra Herrera, 2021).

4.10. Summary

The following table (Table 5) shows which FBL techniques promote which aspects of scientific creativity. The last column indicates the reflection tool(s) used in each FBL technique.

Table 5: List of all interventions and their range on promoting scientific creativity
(TS .. Thinking strategy, TC .. Team competence, P .. Personality)

	Divergent Thinking	Bisociation	Original Association	Imagination Visualization	Meta-cognition
Thinkflex	X	X	-	X	TS
Flex Experiment	X	X	-	X	TS & TC & P
WoSeCo	X	-	X	-	-
Nano Live Act	-	X	-	X	TC & P
Visual Analogy Training	-	X	-	X	-
Memo Tools	-	X	-	X	-
Mind Mapping	-	X	X	X	-

5. Research Results

5.1. Research about the Effectiveness of Flex-Based Learning

To implement FBL techniques in science classes, the individual FBL techniques have been integrated into Austrian textbooks. In addition, a one-year teacher training program has been offered in Austria since 2018. As part of these courses, the FBL concept was evaluated both at the teacher and student levels. More than 100 teachers from Austria have already participated in this FBL teacher training program. In a study (Oyrer et al., 2020) examining the effectiveness of the course at different levels of impact (Kirkpatrick & Kirkpatrick, 2006), 95% of the teachers stated that their methodological competence for promoting problem-solving skills increased significantly through FBL. In addition, the individual FBL techniques were rated as highly practical. Follow-up studies conducted after two years showed a sustainable change in the teaching practice of the participants. Thus, 87% of the teachers regularly used the FBL techniques in their lessons even two years after the course.

For student-level evaluation of FBL, the DPAS test was used in several pilot studies (e.g., Haim & Weber, 2014) and in a validation study (Aschauer et al., 2021). In total, 3,231 Austrian secondary school students (aged 10–18 years) participated in the studies conducted with a two-group repeated-measures design. For each item of the test, fluency and flexibility were obtained. To assess divergent problem-solving ability, the creativity quotient as a composite creativity score including both fluency and flexibility (Snyder et al., 2004) was calculated. A second-order latent difference score approach (McArdle, 2009) was used to model change in the latent means of the DPAS over time. The data from all studies conducted to date show that there was a statistically significant increase in divergent thinking ability within one school year in the intervention classes. On the contrary, no substantial change between pre-test and post-test in the control classes was found.

5.2. Results of the design experiments

Conducting design experiments at all three stages also provided deeper insights into the conditions necessary for fostering scientific creativity, as well as the relationship between theory and practice. As a result of this long-term research project, a huge amount of data has been collected. The central results that could be derived from this are presented below.

Thinkflex

From investigations in the Student Researcher Lab, the authors were able to determine through qualitative surveys that adolescents had great difficulty shifting their thinking perspectives. To facilitate changes in perspective, a perspective check was developed as a graphic representation depicting the most significant perspectives. To ensure that this aid is always present for students during a Thinkflex task, it is included in all worksheets.

In addition, through student interviews, it was shown that students are not highly motivated to solve a Thinkflex task if the task is highly fictional and has little to do with the young people's world of experience. Unreal hypotheticals—such as "Imagine that there is no more gravity on earth ..."—generate very little motivation among young people to engage with a given task. Therefore, when creating the more than 100 Thinkflex tasks that have now been developed, we ensured that the tasks largely originate from the lives of young people and have a certain meaning or relevance for them.

Flex experiment

From the video analyses of the micro-teaching, it could be observed that the test participants often lost their orientation during the open experiment tasks and switched haphazardly back and forth between the respective work phases. Thus, only formulating the problem on a worksheet was overwhelming for many students. Therefore, the authors developed worksheets for all flex experiments that not only contain the problem but also depict all phases of the creative process. Furthermore, by interviewing teachers who used Flex Experiments in their own classes, we learned that it was very irritating for the young people not only to solve a problem in one way but to find several solutions and implement them experimentally. This approach was completely new for the young people, and they also did not see any sense in solving an already solved problem again in a different way. For this reason, when introducing Flex Experiments in their own classes, we recommend that teachers have each team of students implement only one solution. However, the teachers ensure that each student team works on a different solution variation. In the subsequent discussion, the different solutions are presented and reflected upon. This approach demonstrates to the students the value and usefulness of divergent solutions.

The evaluation of the teacher interviews also revealed that low-performing student teams in particular are often overwhelmed during free experimentation. Therefore, the authors developed hint sheets for all Flex Experiments. In the case of being overwhelmed, teams can refer back to these hint sheets and plan the next experimental steps.

WoSaCo
Reflections by teachers during their professional education course revealed that students initially had great difficulty in conducting a WoSeCo. On the one hand, they were not used to linking terms from different chapters, and on the other hand, the meaning of the terms was often not clear enough to them. Therefore, we recommend teachers conduct a written WoSeCo instead of an oral one at the beginning, where the students are also allowed to use the textbook. This gives the young people more time to think about a correct sentence and to get used to the new technique. Furthermore, we recommend teachers create a glossary together with the students from the beginning of the teaching year, in which new technical terms together with their meanings are entered for every lesson.

Nano Live Act
Interviews with teachers who used Nano Live Acts in their lessons revealed that working out a script on their own was a big challenge for the students at first. For example, students found it difficult to focus on the essential elements of the particle level and concentrated, for example, on depictions of the vessel rather than the reactants. To minimize this problem, an introductory variant was developed in which the teacher first takes over the direction of the Nano Live Act, assigning roles to the young people and providing precise instructions on how to perform. In this way, the students learn to focus on the essentials and to design their performance in such a way that it approximates formula writing.

Metacognition
One of the final results from a quantitative study in the professional development course was that many students had very low self-efficacy expectations despite good divergent thinking performance. This effect was significantly pronounced in girls. To improve students' self-efficacy, teachers were encouraged to incorporate metacognitive elements in the classroom, such as having students think about and reflect on personality traits. In this context, the authors are currently developing a reference poster of the main personality traits that can be accessed during student work at any time. An interesting result from the reflection discussions with teachers was also that young people often showed a lack of understanding for a given flex technique and were unwilling to try it out. Only when the teachers explained the meaning, background, and relevance of the flex technique to the students was their willingness to participate significantly

stronger. This underscores the fact that the knowledge about when and why creative thinking is essential has a major impact on the effectiveness of fostering scientific creativity. Adolescents need to be involved in the entire teaching–learning process and should be educated about the relevance of each technique. For this reason, we developed special PowerPoint presentations for students for each technique to inform students what a flex technique is intended to accomplish and why the new technique should be learned.

Listen–Think–Pair–Share Cycle

Both in the lab environment and through observations in the real classroom, we found that this framework creates a safe and anxiety-free learning environment for students, where young people dare to think outside norms and conventions. This increases students' willingness to create original ideas and share them with the class. This aspect is of great benefit in fostering scientific creativity.

6. Discussion and Future Directions

In the literature, several evaluated training programs promote scientific creativity. Using the categorization and terminology of the meta-analysis of scientific creativity interventions from Bi et al. (2020), these training programs can be categorized into the following four groups: problem-solving, collaborative learning, conceptual construction, and scientific reasoning.

The "problem-solving" group includes intervention approaches (e.g., Aktamis & Ergin, 2008) that mainly aim to promote students' problem-solving skills, which are a central component of scientific creativity. Regarding FBL, Flex Experiments in particular would fall into this group. First, this is because they are structured, reflecting the phases of a problem-solving process. Second, parallel to this intervention, students are also informed about the different phases of a problem-solving approach and which thinking style, divergent and/or convergent, is appropriate at which stage.

Interventions in the "collaborative learning" group focus on student collaboration and its associated promotion of knowledge sharing in group discussions. For example, the work of Siew and Ambo (2018), Siew et al. (2017), and Siew and Chin (2018) can be mentioned here. FBL techniques such as Thinkflex or Flex Experiments belong to this group because they follow the Listen–Think–Pair–Share setting. In addition, collaborative learning plays a vital role during Nano Live Acts because students within a group must be responsive to each other's conceptions and constantly share knowledge.

In the "conceptual construction" group, students are supported in developing a coherent and organized knowledge structure for scientific concepts because the associated accumulation of knowledge is an essential component of scientific creativity. For example, the work of Ayverdi and Aydin (2018) and Rasul et al. (2018) can be mentioned here. Regarding FBL, it should be highlighted that interventions like WoSeCo, Memo Tools, Nano Live Act, and Visual Analogy Training not only foster divergent thinking, original association, bisociation, imagination, and visualization but also support students in generating scientific concepts, as well as preserving existing knowledge.

The “scientific reasoning” group includes support programs such as the “Learn to think” program (Hu et al., 2013) or the program of “creative inquiry-based science teaching” (Yang et al., 2016). These programs contain thinking training activities for creative and inquiry activities such as problem-finding, problem-solving, questioning, planning, implementing, and concluding. This group is covered by Thinkflex and Flex Experiments. According to Lawson (2004), scientific reasoning comprises mental plans, strategies for processing information, and rules used to derive conclusions. Thereby, the hypothetical–deductive process is considered the core of scientific reasoning. It involves observing phenomena, generating plausible explanations, deriving conclusions, and finally planning and conducting experiments to accept, reject, or revise the hypotheses. Thinkflex types like “forming a hypothesis,” “finding arguments,” “finding reasons,” or “concluding” train students in these scientific reasoning skills, whereas in flex Experiments, students have to apply these skills.

As shown in the examples above, most training programs comprise only a single type of intervention and focus on one or two aspects of scientific creativity. Therefore, FBL can be described as novel and unique in that it is a collection of several different interventions, covering all essential aspects of scientific creativity. In this sense, the FBL program covers all four categories according to Bi et al. (2020). FBL thus provides a significant contribution to the promotion of scientific creativity in secondary education.

Another unique feature of FBL is that it is easy to implement. Teachers can maintain most of their traditional way of teaching because our program builds on lessons in which basic knowledge and basic skills were taught prior. Most FBL techniques are applied after knowledge acquisition. However, some interventions such as Nano Live Act, or Visual Analogy Training, should be used already in the learning process since they support students in constructing complex scientific concepts. Investigations in FBL teacher training programs showed that Austrian teachers consider the FBL program very feasible and appreciate the developed worksheets and evaluated procedures that can be used directly in the classroom (Oyrer et al., 2020).

There are various concepts related to problem-solving, such as creative problem-solving (Treffinger et al., 2006), complex problem-solving (Dörner & Funke, 2017), and knowledge-centered problem-solving (Friege, 2001). Despite some conceptual differences, all three concepts understand problem-solving as a process that can be divided into several phases. One of these phases is ideation, wherein many divergent solutions are developed. In this phase, divergent thinking, in particular flexibility, is crucial. Since the focus of the FBL program is on promoting flexibility, the authors developed the DPAS test (Aschauer et al., 2021) to assess students’ divergent problem-solving abilities and used this test to explore the effectiveness of FBL. Notably, the impact of FBL on other skills concerning scientific creativity, like the capability for problem-finding, metacognition, or imagination, has not yet been investigated and should be addressed in the future. Furthermore, all results refer to an Austrian sample. Therefore, only limited statements can be made about the general effectiveness of the interventions.

In addition to designing new interventions to promote scientific creativity, another important goal of this research project was to contribute to theories regarding the fostering of scientific creativity in classrooms. This is important because in the existing literature, few empirical studies regarding to this topic exist. In this sense, the research project was designed to be exploratory rather than confirmatory. As outlined in section 5, initial insights can already be gained from the data collected in the design experiments. However, much is still outstanding—for example, how many and which interventions are necessary for an effective program? What gender differences need to be considered? Do all flex techniques or reflection tools contribute equally to fostering science creativity, or do individual techniques stand out? In which age group does one achieve the greatest promotional effect with regard to scientific creativity? In this sense, this paper is also intended to stimulate further research in this field.

Thus far, FBL interventions for secondary education are available for biology, chemistry, and physics. Work is currently ongoing to optimize the existing reflection tools and to adapt the interventions for mathematics and computer science so that the entire STEAM area will be covered in the future. In addition, the individual interventions are also being revised to adapt them for primary-level science teaching. The worksheets and documents for the interventions are currently only available in German. Therefore, they will now be successively translated into English.

To cope with future challenges, young people must learn to solve problems without ready-made strategies. FBL perfectly prepares students for solving real problems. To allow students to work on realistic situations, the authors have developed a course system for students called Creative4Science. Together with flex-based learning, this program forms the backbone of the School of Creative Solutions. This initiative aims to establish schools as think tanks for creative solutions to the challenges of our times. More information about this initiative can be found at www.school-creative-solutions.at.

7. Conclusion

Schools have to prepare students for future challenges by promoting creative thinking skills and problem-solving abilities (DeHaan, 2009; Kind & Kind, 2007; OECD, 2014). For this goal, science education in particular could make a significant contribution. To foster the scientific creativity of secondary students, in the context of a long-term design-based research project, the authors developed the Flex-Based Learning program for the science subjects of biology, chemistry, and physics. The FBL program as a design product can be considered novel and unique for several reasons, including the following: 1) it includes interventions for all different aspects of scientific creativity; 2) FBL promotes divergent thinking and divergent problem-solving in special experimental settings; and 3) most interventions not only promote divergent thinking, original association, bisociation, and imagination but also support students in building up scientific concepts, as well as retaining their existing knowledge.

The design-based research process also pursues the goal of providing contributions to the theory of fostering scientific creativity in classrooms. As a first insight, it became obvious that students' metacognitive knowledge about why and when to think divergently has a major impact on the effectiveness of the FBL training program. Additionally, students need to be supported to generate different solutions, especially in the ideation phase. The developed Perspective Check makes a crucial contribution to increasing divergent thinking abilities. Overall, it seems that Flex-Based Learning is highly effective and can provide essential contributions to the promotion of scientific creativity in secondary science education.

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Appendix 1

Name: Think *flex* Class:

Advantages and disadvantages of fireworks

Some states are considering banning fireworks. Think about as many advantages and disadvantages of using fireworks as possible.

1. Brainstorming

Imagine fireworks and people who are involved in them,
and possibly sketch some thought images on a piece of paper! Now find different advantages and disadvantages by means of **PERSPECTIVE CHECK** and write them down in the table!

WHO benefits from fireworks?	BECAUSE ...
WHO has a disadvantage from fireworks?	**BECAUSE ...**

2. Exchange of ideas

Form small groups and present your pros and cons!

3. Presentation & Discussion

Present and discuss your pros and cons in class! Find ways to group them together. At the end, the class votes on whether they are for or against fireworks!
What alternatives to fireworks can you think of?

21 Topic: **Atomic construction**

PERSPECTIVE CHECK
What ideas do I get when I imagine ...

... how it looks

... how it sounds

... how it smells and tastes

... how it feels

... as it is for people, animals or plants would be

... which advantages and disadvantages there are

... change the place

... change the time

... change the age

Appendix 2

"FIRE OUT!"

Problem

Materials for the problem:

Tealight	Lighter	Aluminum bowl (approx. 250 ml)

First, place a lit tea light in the center of your aluminum bowl.

Find as many ways as possible to extinguish the candle flame using a gas or gas mixture. Implement as many of them as possible! For each subsequent attempt, new chemicals can be made up.

Materials for problem solving:

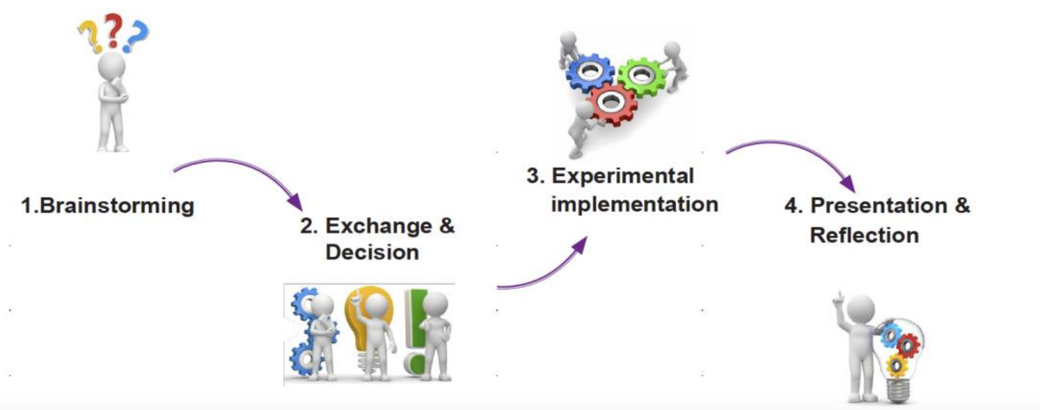
Tablet tube	Water bottle (100 ml)	3 Balloons
Syringe 50 ml	Glove (plastic)	Jam jar (100 ml)
Scissors	Plug - small (with 3 mm hole)	Plug - large (with 5 mm hole)
Aluminum foil (approx. 50 cm)	Hose - short (approx. 10 cm; Ø approx.1 cm)	Hose - long (approx. 25 cm; Ø approx. 1 cm)

For chemical dispensing: 3 measuring cup 50 ml | pen for labeling

1. Measuring cup **Acetic acid solution 5 %** $CHCOOH_3$ (vinegar)  Quantity: 10 ml	2. Measuring cup **Sodium hydrogen carbonate** $NaHCO_3$ ("baking soda") Quantity: approx. 20 g
3. Measuring cup **Effervescent tablet** (contains sodium bicarbonate) Quantity: 1 piece	

Additional material for chemical dispensing: scale with 1 sample spoon

Disposal and cleaning: At the end of the experiment, all solutions are disposed of through the sink. Labels are washed off.



flex FRESH OR SALT WATER

Problem

You will be given two small vials (see collection of materials *), each containing a liquid. In one vial is pure water and in the other salt water (a saline solution).
But you do not know which vial contains which liquid.

Finds as many ways as possible with the help of the available materials, to find out which of the two vials is filled with salt water.

Realize three of them.

The following materials will be provided to you:

2 Vials with liquids*	Measuring cup	Pin
2 Paper clips	Light bulb with socket	Ink
Salt	Luster terminal	Pipette
Battery	2 Cables	Teaspoon
2 Tea lights	Wooden skewer	Igniter
Drinking Straw	Plasticine	Aluminum bowl
Plastic cup	Clothespin	Screwdriver
6 Wire pieces	Scale	2 Measuring cup