Chapter

Full STEAM Ahead with Creativity

Catherine Conradty, Sofoklis A. Sotiriou and Franz X. Bogner

Abstract

The integration of arts in science education (STEAM) aims to provide innovative activities to reach deeper learning levels and generally promote student engagement in (science) education. The European Horizon 2020 project CREATIONS with 16 partner institutions addresses this challenge with more than 100 initiatives over three years. All initiatives followed our STEAM guidelines based on the fundamental principles of responsible research and innovation (RRI). The positive effects of STEAM on cognition and motivation were evident in all initiatives with a sufficient empirical database. Besides the intention to integrate creativity, our study focused on flow that is experience of total immersion and exhilarating absorption in an activity that is experienced as effortlessly mastered. The productivity resulting from the self-rewarding creative rush makes flow particularly interesting. This chapter contributes to the open question of how flow is triggered with an exemplary meta-analysis of motivation and creativity scores of ten interventions ranging from complex projects at CERN to art-centred, play-based, laboratory-oriented projects or almost classical school initiatives. The regression analysis decoded self-efficacy as the crucial factor enabling the flow experience—which was demonstrated in this study for the first time, moreover, in a variety of age groups in the context of classroom activities.

Keywords: creativity, flow, self-efficacy, secondary school students, arts and science, STEM, European-wide study

1. Introduction

The need of creativity in science has been highlighted over the last 50 years [1]. Researchers such as Moravcsik [2] allocated creativity even as the key element of science (education): "Without [creativity], science turns into a sterile manipulation of fixed rules and their embellishment without any tangible result, whether in the conceptual or practical sense" (p. 222). Science, like arts, requires a high degree of open network thinking and the ability to question established knowledge to ask the right question and find the appropriate ways to answer it [3]. Both, scientists and artists alike, are fond of understanding the world although their methods and choice of means differ and often misunderstand each other by disregarding potential benefits. A well-known historical example is Leonardo daVinci, who acted as both, a scientist and an artist. His scientific work on mechanics, proportions or anatomy is hardly distinguishable from art, and one would not have been possible without the other.

It has been a long definition process of creativity as it is a rather complex construct [4]. Starting from a rather general definition which regards creativity as a pivotal competence to solve current problems and to meet the requirements of the post-industrial age [5, 6], the view became increasingly broader as the complex problems of our global, post-industrial culture required education that fostered skills such as self-responsibility, creativity and reflection [7]. Dealing with that requires complex products that need multi-level creativity to develop [8]. For a possible solution, the ability to generate and pre-select ideas through imagination is needed [9]. Thus, creativity is not only declared to be the key element of science [2] but is also considered to be the key competence of the twenty-first century [10]. Reactive real-time creativity is characterized by spontaneity with improvisational and immediacy skills [9]. This high level of cognitive creativity is not innate and requires constant training. Hsu [11], for instance, indicated an incubation period prior to creativity as crucial for various individual traits relevant to creativity.

Today, as knowledge is always accessible and with constant updates, it seems to be increasingly an erroneous path to teach knowledge instead of creative competencies. Formerly, education was optimized for standardization and conformity, leading to compulsory curricula and strict testing requirements. Arts was reduced to a mere element of subject teaching, ignoring more or less the essence of creativity rather than using it as an element of learning across all classroom subjects [12]. For a long time, little had changed in the curricula. Nowadays, a fundamental shift in teaching objectives is emerging, away from the traditional teaching of "knowledge" (cognition) toward the promotion and development of students' "skills" (competence orientation) [13]. After the extensive discussion of art and the definition of creativity and the investigation of the connections, STEAM instead of STEM is now gradually finding its way into the classroom.

Because of its importance in science, creativity is recognized as a critical component of STEM at school [14, 15]. Many educators consider science as creative and regard the relationship between knowledge and creativity in science as a special opportunity [16]. Creative approaches in science education are supposed to generate alternative ideas and foster everyday creativity, which results in purposive, imaginative, activity-generating outcomes. Although creativity is not limited to a particular subject area, Torrance [15] argued that science offers a much broader range of activities that can be used to foster creativity than other school subjects. The process of creativity, preparation, incubation, illumination and verification, follows similar steps to the scientific method: observation, hypothesis, experiment and verification [17, 18]. All scientific processes require a creative mind: hypothesis generation and observation require high levels of open-mindedness to experience and sensitivity, which in turn are components of creative thinking [19–21].

Despite the emergence of Science, Technology, Engineering, Arts, Mathematics (STEAM) as a popular pedagogical approach to foster students' creativity, problem-solving skills and interest in STEM subjects, definitions and goals of STEAM education remain inconsistent [22]. The Horizont2020 STEAM project CREATIONS was set up to support this link by including partners from different fields for preparing and implementing innovative examples of STEAM [23]. A roadmap guided the development of more than 105 interventions within the three-year project period. The idea in a nutshell: why are students more creative in their leisure time than in school and how can school be designed to provide the same research environment as creative leisure time [24–27]?

All STEAM interventions followed the key principles of Responsible Research and Innovation (RRI). The creative elements followed the 5E teaching model by proposing the five phases: engagement, exploration, explanation, elaboration and evaluation

Creativity killer (modified after [34]	Creativity supporter (CREATIONS)
Surveillance: Hovering over students, making them feel as if they are constantly being monitored while they are working	Student-oriented **self-regulated** learning environment with a teacher as a tutor;
Evaluation: Making students worry about how others judge what they are doing	Students and teachers in the role of research colleagues; excellent **error management culture**: There are no failures, only experiences with falsification of an experiment;
Competition: Putting students in a win/lose situation in which only one person can come out on top	Confidence within the **team**; each team member contributes valuable;
Overcontrol (perfect structured lessons): Telling students exactly how to do things and forbidding any exploration	Well-prepared **working material** for self-regulated learning with space to elaborate and even fail;
Pressure (closely defined goals): Establishing grandiose expectations for a student's performance.	*Error management culture:* **open-minded** for new, even unconventional proposals. Everything is a step toward a bigger goal;

Table 1.
Killer of creativity and supporters.

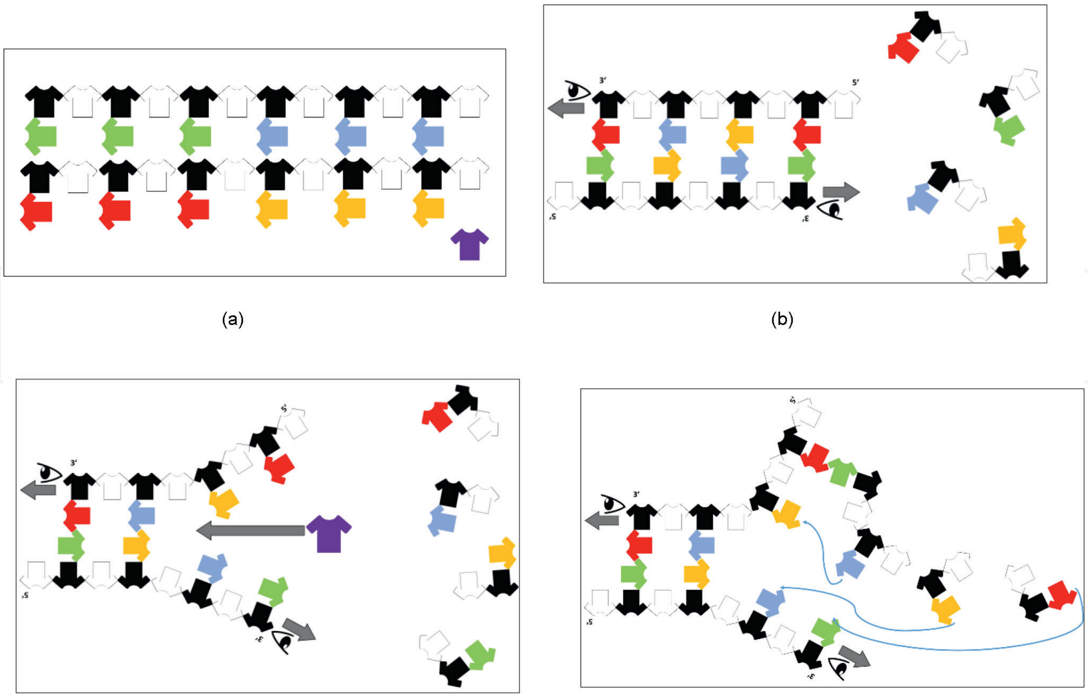
[28, 29]. Creativity was integrated in the classroom environment as students were able to imagine, explore, experiment, test, manipulate, take risks and speculate as well as to make mistakes [30]. Inquiry-based learning in the CREATIONS modules promotes deeper learning [31]. What has been worked out independently is understood and thus rarely forgotten but transferred and used in other contexts [32]. Special attention was given to the creativity supporters as well as of "killers" in learning environments (**Table 1**) [33].

Teachers offered this creativity-supporting social environment by adopting the role of a tutor [62]. They were responsible for a well-structured learning environment but left enough room for self-responsibility to deal with problems and scientific questions [35, 36]. This provides space for self-experience; it practices dealing with failure in a safe environment and recognizes failure as an elementary part in scientific work [37]; furthermore, this way of teaching supports self-efficacy because every increase in knowledge and success is based on students' own work [34, 38]. As an example of some of the teaching interventions analyzed, we briefly describe the structures below. These show the variability in which the basic structure of a CREATIONS intervention can be applied.

Gen-ious is an intervention carried out in a student laboratory in addition to the classroom. The engagement with the technology-loaded genetics lab and the DNA replications model, which has a reputation for being complex, is split up by a creative inquiry-based construction phase. Students can craft models that can symbolize the DNA structure while observing the creativity facilitators. The lightness and playful creativity relieve the fear of making mistakes, which would basically reveal misconceptions that can then be identified and corrected on one's own. With the creative teaching structure, the motivation to finish difficult (thought) processes, work on science and learning increased, as did long-term learning performance. More information about the intervention design of *Gen-ious* is described in [39, 40].

Art of Flying—the Jurassic fossil bird Archaeopteryx. The instructional content of the module on bird flight approached the topic in an interdisciplinary way with biology and physics. Introductory phase and final plenary provided the safe framework in which the teacher provided rules and basic information about the work processes. Within this framework, the students worked cooperatively in small groups of 3–4 participants (assembled by free choice) and completed the working stations' tasks autonomously. With a focus to support self-efficacy, tutoring should be provided without negative feedback or too much help. For this, not the teacher but instead a workbook with instructions for each task supported the autonomous learning process. The educational module followed the concepts of open Inquiry-Based Science Education (IBSE) by integrating elements of creativity and arts to extend STEM to STEAM instruction. Within the creativity approach, the arts aspect in science education was applied via two workstations with collaborative handicraft artwork on natural fossils and paper glider models [41, 42] (**Table 1**).

DNA-dance—simulating a double helix in schoolyards. As an example of involving one cohort of a total school, that simulation game was implemented within a schoolyard (**Figure 1**). All 7th-graders assembled in the schoolyard by wearing six different colors of T-shirts: white (= Desoxyribose) and black (=phosphate) formed the helix backbone, while blue, green, red and orange symbolized the different bases (cytosine, guanine, adenine and thymine) containing the genetic information (purple = enzyme helicase). Half of the cohort danced in the manner of a row dance and symbolized a double helix (see **Figure 1**; 1 + 2). In the second step, the double helix has been split up by the appropriate enzyme helicase (see **Figure 1**; 2 + 3). In order to duplicate the double helix, the other half of the cohort substituted the emptied places and finalized two identical separate double helices (see **Figure 1**; 3 + 4). In summary, this inquiry-based laboratory module about



(a) (b) (c) (d)

Figure 1.
DNA—Dance in a school yard: Dancing scheme for the replication of a short double-stranded DNA molecule. 1. The students with the T-shirts symbolizing the single "players" of a DNA-double helix 2. Preparation: "Constructing" a double-stranded DNA molecule. 3. Separating the double helix into strands with the enzyme helicase. 4. Complementing each strand by supplementing base-pairings with free nucleotides fitting in a 5′ to 3′ direction.

genetics needs about one lesson and, beforehand, theoretical background knowledge by regular classroom lesson about genetics.

Altogether, the STEAM CREATIONS projects addressed all areas of science (Physics, Mathematics and Biology). We investigated the relationship between self-efficacy and flow. Flow is often misjudged as a special feeling of happiness of talented artists. Due to the positive effects of flow experiences on well-being and productivity, the feasibility of consciously provoking flow in everyday life is being explored. The present study investigates the hypothesis that self-efficacy experiences can trigger flow. For this purpose, students participated in creative STEAM projects that were developed according to CREATIONS guidelines and monitored by a pre-post-test evaluation design.

2. Methodology

Students completed an online questionnaire before and after participation. Bias was avoided as participants were never aware of any testing cycles [43]. The basis of subject selection was participation in the standard test design. We applied the subscale “self-efficacy” of the science motivation questionnaire [44], using a 5-point Likert scale pattern ranging from “never” (1) to “always” (5). To improve applicability, we have chosen the four best-loading items of each subscale. The strong factor structure of the total toolset allows for this reduction in the item count, which has been confirmed in many studies [45–47].

For creativity measurement, we focused on the level of motivation and attitudes associated with personal creativity, as well as on the cognitive (thinking) and non-cognitive (motivation) dimensions of creativity [4]. We applied two subscales modified by [48]: “Act” quantifies cognitive processes of conscious and active thinking which can be trained and taught. “Flow” monitors typical elements of an individual flow experience [1] which is supposed to assess motivational experiences at school related to creativity. The creativity measure employed a 4-point Likert scale ranging from “never” (1) to “very often” (4). For the present analysis, we focused on flow.

Data from ten randomly selected projects with large numbers of participants with pre- and post-tests were analyzed (N per project: 100–330). In the total data set, complete question sets of 1358 students (aged 10–18 years, M ± SD = 12.82 ± 2.6) were analyzed. The gender ratio was almost balanced with 51% female students. This proportion by chance was the same in all STEAM implementations.

For statistical analyses, IBM SPSS Statistics 29.0 was used. Outliers were rejected. Following the central limit theorem, we assumed normal distribution of the data [49], p. 9. A Wilcoxon test was applied to calculate potential differences in gender. A regression model was calculated with flow as the dependent variable and SE, age and gender as predictors. We calculated this regression model for both the pre-test and the post-test data.

3. Results

No gender effects appeared. To analyze the dependence of flow on self-efficacy, a regression model was calculated with flow as the dependent variable and SE, age and gender as predictors. We calculated this regression model for both the pre-test and the post-test data.

The technical prerequisites for the regression were given in both data sets: After analyzing the student-sampled excluded residuals, only four outliers were excluded. Leverage and Cook distance showed no outliers. The P–P diagram of standardized residual suggested normal distribution. The Durbin–Watson statistic suggested that

	R	R^2	Corrected R^2	Durbin–Watson statistic
Pre-Test	.335	.112	.119	1.720
Post-Test	.469	.220	.218	1.659
Influencing variables: (constant), SE, gender and age; dependent variable: Flow				

Table 2.
Model summary of regression analysis (incl. The influencing variables).

		df	F	sig.
Pre-Test	Regression	3	56.935	<.001
	Non-standardized residuals	1355		
	total	1358		
Post-Test	Regression	3	106.200	<.001
	Non-standardized residuals	1129		
	total	1132		
Influencing variables: (constant), SE, gender and age; dependent variable: Flow				

Table 3.
ANOVA of regression analysis (incl. The influencing variables).

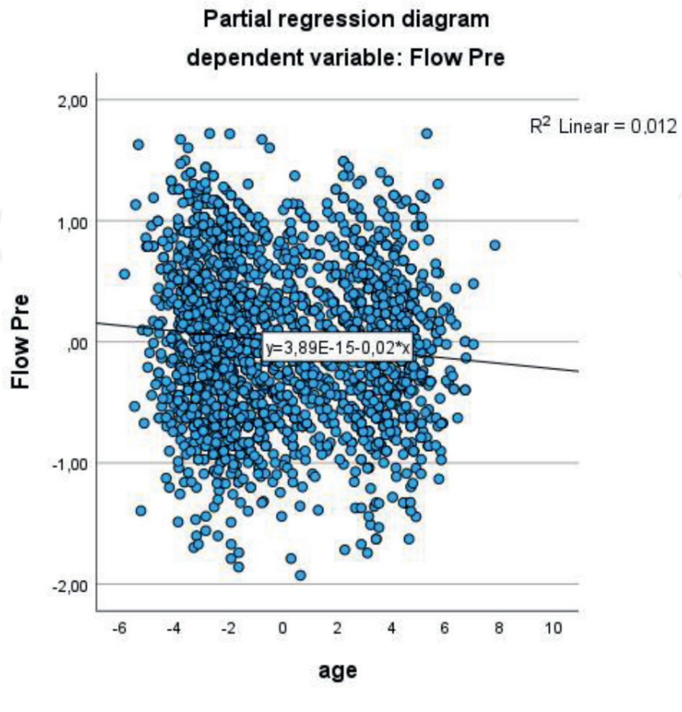


Figure 2.
Scatterplot of residuals illustrating the relationship between age and flow. Pre- and post-test showed an identical trend (not illustrated here).

there was no autocorrelation (**Table 2**). The Pearson correlations proved the data set to be very suitable with Person Corr. max. 0.387 (which should be <0.7). Multicollinearity was excluded with values above 0.77 (tolerance openness: 0.838; treatment 0.773; SE 0.914) (tolerance should be >0.1). Homoscedasticity of the residuals

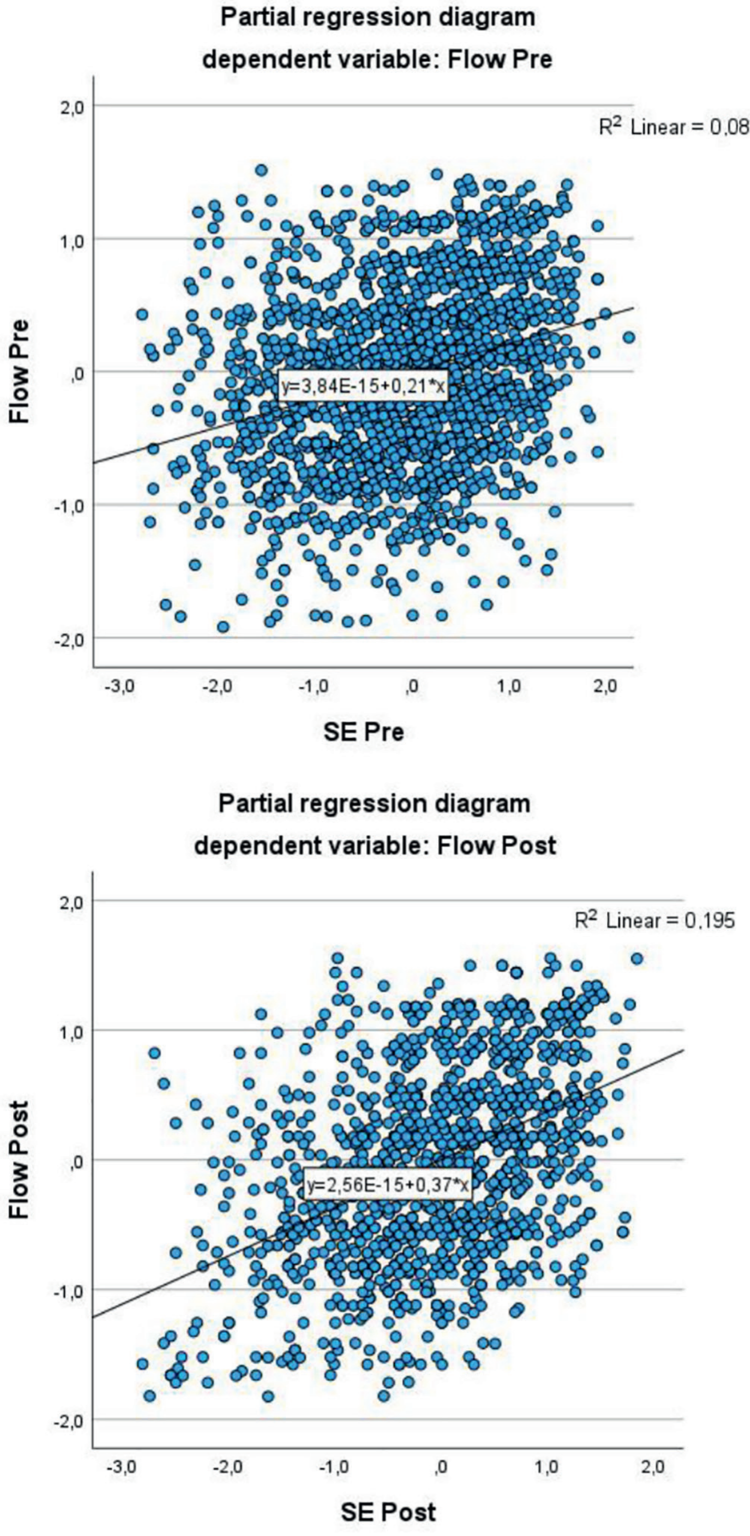


Figure 3.
Scatterplot illustrating the relationship between SE and flow. Pre- and post-test show the similar trend upper vs. lower plot, whereby it is stronger for post-STEM scores lower plot.

was ensured, which indicated that our model did not make better predictions for some values than for others.

Thus, all prerequisites for a meaningful interpretation of the regression analysis of the two data sets were proven. For the post-test data, collected after students participated in a STEAM intervention following the CREATIONS guideline, the R for the overall model was 0.48 (adjusted $R^2 = 0.22$), indicative for a high goodness-of-fit according to Cohen [50] (**Table 2**). Self-efficacy, gender and age were able to predict flow statistically significantly, $F(3, 1129) = 106.200$, $p < 0.001$ (**Table 3**). Even in the pre-test, when students have never received explicit creativity-enhancing STEAM education, the effects of SE, gender and age on flow were found. The R for the overall model was 0.34 (adjusted $R^2 = 0.11$), indicative for a medium goodness-of-fit according to Cohen [50] (**Table 2**). Self-efficacy, gender and age were able to statistically significantly predict flow, $F(3, 1358) = 56.935$, $p < .001$ (**Table 3**).

The effect of the predictors gender and self-efficacy on flow can also be seen in the scatterplots. There is a trend toward a decrease in flow with increasing age. This is identical at both test times (**Figure 2**). Self-efficacy strengthens the ability to experience flow. This strengthening of flow through SE became even stronger in the post-test (**Figure 3**).

4. Discussion

CREATIONS projects implementation has demonstrated innovative approaches and activities that involve teachers and students in scientific research through creative ways that are based on art and focus on the development of effective links and synergies between schools and research infrastructures to spark young people's interest in science and in the following scientific careers. In this framework, the present work demonstrates self-efficacy experiences as a trigger of flow which is considered to greatly contribute to students' motivation and achievement in science [51]. Work in the field highlights the role of time, place and attention for setting up conditions for flow experiences, in general, and in scientific inquiry in particular [52]. Furthermore, the use of innovative tools and advanced technologies contributes to both student performance improvement and the appearance of flow [53].

Not physiology but also culture may cause gender differences [54]. Csikszentmihalyi [55] reported that traditional gender discrimination in education determines how boys and girls develop. In line with other studies in Germany [32, 42, 56, 57], this meta-analysis of various STEAM projects found no differences, probably suggesting a gradually changing gender equality culture. Education that naturally integrates all genders ensures that it is less social desirability and more personal interest that decides which talents and career aspirations young people develop [58]. The teacher's attitude in particular can be inspiring in role development [59, 60]. Teachers may educate students to become creative democrats, but they need a modern, open-minded attitude as tutors of scientifically working students [61]. Such teacher trainings need modern forms that train the development of attitudes and ways of communication [62].

In our CREATIONS project, designing a number of learning experiences was the main focus that met the conditions for the development of flow. The term "experience" plays a special role in the framework of the current study and is defined as perceiving, discerning or understanding something that stands out in the student's consciousness, or how personal experiences stand out in their consciousness [63]. Students had numerous chances to pose questions and explore techniques and various approaches, or they were given a scientifically oriented question to investigate. Balance and navigation through dialog supported teachers and students in creatively solving educational tensions. Questions arose through dialog between students', professionals' and educators' scientific knowledge or through dialog inspired by interdisciplinary and personal, embodied learning.

Ethics and trusteeship were important considerations in experimental design and collaborative work, as well as in the initial choice of question. Students gave priority to evidence, which came from individual, collaborative and communal activity such as practical work or from sources such as data from professional scientific activity or from other contexts. To maintain the flow experience, we had to restore the balance between challenges (situations in which a student has major freedom of action) and skills (the capabilities or tools that a student needs to be able to cope with a challenge like and experiment or a project) [1]. One of the things analyzed in our study was what characterizes the students' approaches to restore this balance in group work while working with 3D environments and visualizations. Immersion and play were crucial in empowering pupils to generate, question and discuss evidence.

Students used evidence they had generated and analyzed to consider possibilities for explanations that were new to them. They used argumentation and dialog to decide on the relative merits of the explanations they formulated, playing with ideas. Students connected their explanations with scientific knowledge, using different ways of thinking and knowing to relate their ideas to both disciplinary and interdisciplinary knowledge to understand the origin of their ideas and reflect on the strength of their evidence and explanations in relation to the original question. Experiencing a phenomenon is the same as discerning aspects of the phenomenon in question [61]. For this to be possible, the student must be given opportunity to experience multiple aspects of the same phenomenon simultaneously [64]. This means that students need to be able to compare their previous experiences with the current one and then to adopt them for applicability in solving a problem in a new situation.

Communication of possibilities, ideas and justifications through dialog with other students, with science educators and with professional scientists offered students the chance to test their new thinking and to be immersed in a key part of the scientific process. Such communication was crucial to an ethical approach to work scientifically. Finally, it has to be noted that individual, collaborative and community-based reflective activity for change both consolidates learning and enables students and teachers to balance educational tensions such as that between open-ended inquiry learning and the curriculum and assessment requirements of education. This is likely to be an appropriate form of feedback that reinforces students' self-efficacy and thus enables flow experiences.

Having created the conditions for the development of flow, our analysis indicates that the conditions the students have at their disposal to create a balance between challenges and skills relate to the intended projects and activities that they were involved. The results of this study show that the versatility of the proposed STEAM approach offers a modular framework for the design of similar activities in the field. The analysis of the students' work on the selected challenges in the different learning settings shows that variation exists in the balance between skills and challenges.

This study shows that we can systematically analyze characteristics of flow within the framework of inquiry lessons in science. Although this study does provide an applicable flow model and offers certain insights into some of the generic properties of flow, it is too early to specify how the model can be used in various science lessons.

Further systematic research is needed, and the concepts should be studied in other areas to see if similar conclusions can be drawn.

Acknowledgements

This work was supported by the European HORIZON-2020 framework, in detail by CREATIONS—Developing an Engaging Science Classroom (Grant Agreement No.665917; http://creations-project.eu). Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the position of the founding institutions. We are very thankful to all project partners for steadily supporting the vision and, last but not least, to all students and teachers for implementing the modules and completing all the questionnaires. Additionally, we thank T. Baierl for reading the final paper versions.

Funding

This research was funded by the Horizon 2020 Framework Program (grant number 665917) as well as by the University of Bayreuth and the Ellinogermaniki Agogi. Funded by the Open Access Publishing Fund of the University of Bayreuth (German Research Foundation, grant number LA 2159/8-6).

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