Scientific Research Publishing

Creative Education, 2025, 16(4), 495-519
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Bridging Art and Science: STEAM Lessons and Their Impact on Pupils' Learning Motivation Characteristics

Julia Lauss, Christoph Helm

Department for Educational Research, Johannes Kepler Universität Linz, Linz, Austria
Email: julia.lauss@jku.at, christoph.helm@jku.at

How to cite this paper: Lauss, J., & Helm, C. (2025). Bridging Art and Science: STEAM Lessons and Their Impact on Pupils' Learning Motivation Characteristics. *Creative Education, 16,* 495-519.
https://doi.org/10.4236/ce.2025.164030

Received: March 7, 2025
Accepted: April 19, 2025
Published: April 22, 2025

Abstract

The integration of arts into science education is increasingly recognized as a means to enhance both cognitive and non-cognitive learning outcomes. This study examines whether the incorporation of art elements into STEM lessons influences pupils' motivation, self-efficacy, flow experience, and subject-specific interest. A longitudinal design was employed, with data collected from 471 pupils across eight schools at two measurement points. The findings indicate a significant increase in self-efficacy, subject-specific STEM interest, extrinsic regulation and interest in art among pupils who participated in the intervention. These results suggest that artistic activities not only make STEM subjects more engaging but also foster a broader appreciation for the arts. The study highlights the potential of interdisciplinary teaching strategies in enhancing motivation and self-efficacy, offering valuable implications for educational practice and future research.

Keywords

STEAM Education, Self-Efficacy, Learning Motivation, Art Integration, Longitudinal Study, Creativity, Arts-Based Teaching

1. Introduction

The shortage of skilled STEM professionals is a growing concern in many countries, including Austria, where declining enrolments in STEM fields exacerbate this issue (Dibiasi et al., 2024; OECD, 2022). Reports indicate that the demand for STEM professionals continues to outpace enrolments (European Commission, 2023), highlighting the need for strategies that foster pupils' interest in STEM disciplines (Caprille et al., 2015). Misconceptions about STEM being overly demanding deter pupils, underscoring the importance of innovative teaching approaches (Boiko et al., 2019). In response to these challenges, education systems must not only impart domain-specific knowledge but also cultivate cross-disciplinary skills such as creativity, critical thinking, and problem-solving (Fensham, 2022). Self-determination theory (Deci & Ryan, 1993, 2008) provides a well-established framework for understanding how open learning environments can foster learner autonomy, motivation, and engagement (Herro et al., 2017).

While inquiry-based and interdisciplinary learning formats have been widely studied in science education (Meulenbroeks et al., 2024; Sung et al., 2023; Connors-Kellgren et al., 2016), the integration of the arts into STEM education (STEAM) remains underexplored despite its potential to enhance pupil motivation and engagement (Belbase et al., 2021).

This study investigates the impact of integrating arts into STEM education on pupils' motivational characteristics in eight secondary schools. Specifically, we examine whether art integration can stimulate pupils' interest in STEM subjects and enhance their learning motivation. To address these questions, we employ a longitudinal design with two measurement points within a trial group and control group framework. The findings contribute to the growing discourse on STEAM education and its role in fostering key 21st-century competencies.

1.1. The Role of Arts Integration for Learning Relevant Forms of Pupil Motivation

Motivation is vital to academic success as it significantly influences pupils' engagement, persistence, and willingness to actively interact with learning content (Howard et al., 2021). The study of learning motivation has a long tradition in educational psychology, incorporating diverse theories (e.g., Urhahne, 2008). In the present study, self-determination theory (Deci & Ryan, 2008) and self-efficacy theory (Bandura, 1986) serve as the primary frameworks to investigate how integrating art into STEM education can enhance motivation, self-efficacy, flow and sustained interest in STEM subjects, all of which are central variables in our research.

The self-determination theory (Deci & Ryan, 1993, 2008) emphasizes three fundamental psychological needs for fostering intrinsic motivation and well-being: autonomy, competence, and relatedness. Art integration can promote these needs in many ways. In art-integrated science lessons, pupils might be given the choice to select their preferred medium, such as painting, sculpture, or digital design to represent a scientific concept. This freedom to decide fosters self-directed learning and enhances the sense of autonomy. Engaging in creative activities, such as experimenting with different artistic techniques to illustrate a complex process, allows pupils to receive feedback and refine their skills. For instance, developing a visual model of a scientific phenomenon and discussing it with peers and teachers can help them feel more capable and effective. Collaborative projects, such as designing a group mural depicting a natural ecosystem, encourage teamwork and open communication. This cooperative environment supports social connectedness and fulfills the need for relatedness. Moreover, these art-based activities can induce a flow experience, characterized by complete absorption and enjoyment, which is closely tied to intrinsic motivation (Csikszentmihalyi, 2000; Madison et al., 2019; Howard et al., 2021).

Bandura's (1986) self-efficacy theory centers on the belief in one's own capabilities to successfully perform tasks and overcome challenges. Art-integrated STEM education can nurture several key sources of self-efficacy. By engaging in creative tasks such as dramatizing a scientific process or constructing an art project that represents a scientific principle, pupils gain hands-on experiences that validate their abilities. Observing peers succeed in interpreting complex scientific content through art can reinforce a pupil's own belief that they, too, are capable of mastering the task. Continuous feedback and encouragement from teachers and fellow pupils during art-based projects serve as verbal reinforcement, boosting self-efficacy. The playful, low-pressure atmosphere of art-integrated lessons helps reduce anxiety and stress, creating positive emotional states that further support a strong sense of self-efficacy.

Both theories underscore not only the enhancement of motivation but also the development of a sustained interest in STEM subjects. When pupils experience autonomy, competence, relatedness, and increased self-efficacy through creative and engaging activities, their intrinsic interest in the subject matter deepens (Sansone & Smith, 2000). This interest is critical, as it contributes to long-term engagement and academic success.

Thus, by integrating art into STEM education, the teaching approach targets the very elements that can transform situational engagement into enduring academic interest. This theoretical foundation provides a clear rationale for our study, which empirically investigates how art integration influences motivational development and interest in STEM subjects.

1.2. The Effect of Arts Integration in STEM Education on Motivational Characteristics

While numerous studies have examined ways to enhance motivation through innovative learning models such as inquiry-based learning (Baeten et al., 2013), fewer studies have explicitly investigated the role of art integration in this context. The present study extends these approaches by exploring whether integrating artistic elements into STEM lessons influences pupils' motivation, self-efficacy, flow experience, and subject-specific interest. Existing research on innovative learning approaches emphasizes active, independent exploration and problem-solving as key to fostering a deeper understanding of scientific concepts (Baeten et al., 2013). Adding artistic engagement introduces an additional dimension to learning, allowing students to grasp abstract scientific content not only cognitively but also visually and emotionally. This connection may lead to a deeper engagement with scientific topics and a more sustained motivation to learn (Meulenbroeks et al., 2024).

Effects on Cognitive Learning Outcomes

Although this study does not focus on cognitive changes perse, previous research suggests that increased personal competence can positively influence motivation (Deci & Ryan, 2008). Studies have shown that integrating the arts into education can enhance subject-specific interest by making learning more engaging and meaningful. A meta-analysis by Lee et al. (2020) investigated the effects of theatre pedagogy on academic performance, motivation, and artistic ability. The findings indicated that artistic approaches were particularly effective in language instruction, raising the question of whether similar benefits extend to STEM subjects.

Similarly, Catterall et al. (2012) analyzed data from the National Education Longitudinal Survey, revealing that high artistic engagement correlates with improved academic outcomes, particularly among socioeconomically disadvantaged students. These students achieved higher grades, had higher enrollment and graduation rates, and demonstrated overall positive academic development. Given that subject-specific interest is a critical predictor of long-term engagement in a field (Holstermann et al., 2010), it is crucial to investigate whether integrating art into STEM lessons can foster a lasting interest in science.

Effects on Non-Cognitive Learning Outcomes

The integration of arts into education has been linked to various non-cognitive benefits, including increased self-efficacy, intrinsic motivation, and flow experiences. Schraw et al. (2006) highlighted the role of self-regulation in science education, arguing that learners who can control their learning processes achieve better outcomes. They emphasized the importance of metacognition, reflecting on one’s own thinking, and intrinsic motivation in fostering engagement. Artistic activities, which encourage experimentation and creative problem-solving, provide similar opportunities for self-regulated learning.

Bandura’s (1986) self-efficacy theory suggests that individuals who believe in their ability to succeed are more likely to engage in and persist with challenging tasks. Conradty et al. (2020) found that creative engagement in science lessons led to increased self-efficacy, as students gained confidence in their ability to solve complex problems through artistic means. DeMoss and Morris (2002) reached similar conclusions in their evaluation of the Chicago Arts Partnership in Education (CAPE) project, which demonstrated that art-integrated learning fosters a perception of academic challenges as opportunities rather than obstacles.

Self-determination theory (Deci & Ryan, 2008) distinguishes between different types of motivation, ranging from intrinsic (engaging in an activity for its own sake) to extrinsic (engaging due to external rewards or pressures). Art-based learning environments have been shown to enhance intrinsic motivation by allowing students to express themselves creatively (Soomro et al., 2023).

Flow, as described by Csikszentmihalyi (2000), refers to a state of deep concentration and enjoyment in an activity. Previous research suggests that artistic activities can facilitate flow by engaging students in immersive and personally meaningful experiences (Madison et al., 2019). However, if creative tasks are perceived as too ambiguous or cognitively demanding, they may instead disrupt flow.

Interest theory suggests that situational interest (triggered by engaging activities) can develop into long-term individual interest if supported by continued exposure and positive experiences (Hidi et al., 2004). While previous studies have demonstrated that arts integration can enhance general engagement in education (Catterall et al., 2012), fewer studies have investigated whether it specifically influences students' interest in art or their subject-specific interest in STEM. The current study aims to fill this gap.

The Role of Socioeconomic Background

Socioeconomic background has been identified as a significant factor influencing academic performance and motivation. The most recent PISA results indicate that socioeconomic status has a considerable impact on student achievement in Austria, with a 106-point difference in mathematics scores between the highest and lowest socioeconomic quartiles (Toferer et al., 2023). Given that prior research (Catterall et al., 2012) suggests that arts integration may benefit socioeconomically disadvantaged students, this study also explores whether the effects of art-integrated STEM education vary based on students' first language and parents' profession.

While previous research has demonstrated the benefits of arts integration in education, several gaps remain. On the one hand, few studies have systematically examined its effects on a broad range of motivational characteristics in STEM education. On the other hand, limited research has investigated how these effects vary across different student groups, particularly in relation to socioeconomic background.

By addressing these gaps, this study builds on existing literature and provides empirical insights into the impact of arts integration on STEM motivation. The findings will contribute to both theoretical understandings of interdisciplinary learning and practical recommendations for the design of effective STEAM initiatives.

1.3. Research Aims and Hypotheses

The primary aim of this study is to systematically examine how integrating the arts into regular STEM lessons influences pupils' motivational learning characteristics. In particular, the study seeks to answer the following research question:

Which motivational learning characteristics of pupils can be influenced by the integration of art into the classroom, and does this effect differ across socio-economic groups?

Art integration in education has been shown to initiate both cognitive (Lee et al., 2020) and non-cognitive changes (DeMoss & Morris, 2002), with motivation playing a central role in both. Drawing on self-determination theory (Deci & Ryan, 2008), self-efficacy theory (Bandura, 1986), and the concept of flow (Csikszentmihalyi, 2000), previous research indicates that creative, art-based interventions can enhance key motivational components such as intrinsic motivation, perceived competence and sustained interest. For example, art-integrated lessons have been linked to increased autonomy and competence (e.g., through choice of creative expression and collaborative projects), higher self-efficacy (via mastery and vicarious experiences), and the promotion of both situational and enduring interest in learning subjects.

Based on these theoretical insights and empirical findings, we derive the following hypotheses: For pupils participating in art workshops in STEM classes, greater increases are expected in the areas of intrinsic regulation (H1), identified regulation (H2), introjected regulation (H3), extrinsic regulation (H4), flow experience (H5), self-efficacy (H6), interest in art (H7), and subject-specific interest (H8) than for pupils who do not participate in art workshops in STEM classes.

Furthermore, in line with our research question addressing socio-economic differences, the study also investigates whether the effects outlined in Hypotheses H1–H8 are moderated by pupils' first language and their parents' profession. This additional analysis aims to clarify if art integration has a differential impact across diverse socio-economic groups.

Through this framework, the study not only builds on previous research by extending the established benefits of inquiry-based and collaborative learning but also addresses the research gap concerning the unique role of creative arts in enhancing motivational characteristics within STEM education.

2. Materials and Methods

2.1. Intervention

In this study, the integration of art into the curriculum involves workshops led by artists within regular class sessions. The project spans three school years during which the artists hold workshops lasting 7 - 9 weeks annually in a chosen STEM subject. These workshops are designed to cover and reinforce curriculum topics for each grade level, ensuring that no additional instruction on the chosen subject matter by the teacher is necessary afterwards. The workshops took place in the summer semester of 2022-2023 across all participating schools. These workshops were led by professionals specialising in areas such as theatre, improvisation, choral theatre, performance, music, radio, percussion, and dance. As part of the project, they integrated artistic methods such as storytelling, dance, and improvisational theatre to convey scientific content and foster interdisciplinary learning. For example, in workshops on climate change, students developed small theatre performances where they embodied different elements of the ecosystem, making complex scientific processes more tangible. Similarly, in a workshop on sustainable mobility, students designed and performed a movement piece representing different modes of transportation, showcasing the impact of individual mobility choices on the environment. In another project on the architecture of the future, students used visual arts and performance to create interactive models of sustainable cities, exploring innovative building materials and energy-efficient designs.

Even fundamental scientific concepts like atomic bonding were creatively approached through dance and movement exercises, allowing students to physically represent molecular structures and interactions. Additionally, some workshops introduced students to media production as a means of artistic and scientific exploration. For instance, in one particularly innovative workshop, pupils collaborated to produce their own radio broadcasts. These broadcasts, aired on a local station, required pupils to creatively engage with STEM topics while working with recording technologies and editing software. Such hands-on activities not only reinforced STEM content but also introduced pupils to technological tools, enhancing their media literacy and practical skills.

By embedding these diverse artistic approaches within STEM education, the project aimed to deepen students' understanding of scientific concepts while fostering creativity, engagement, and interdisciplinary thinking.

2.2. Sample

The 3-year longitudinal project involved five secondary schools with seven project classes (trial groups). In addition to the project classes, 11 classes participated as a control group. To ensure similar conditions, the measurement repetitions in all the control classes were also conducted approximately eight weeks after the initial assessment. Data were collected from Ntotal = 471 pupils (average age: M = 11.96 years, SD = 1.13; 248 females, 223 males). Of these, Ntrial = 245 pupils (average age: M = 12.07 years, SD = 1.09, 144 females, 101 males) were directly involved in the project, and Ncontrol = 226 pupils (average age: M = 12.17 years, SD = 1.31, 104 females, 122 males) were assigned to the control group.

2.3. Instruments

The quantitative data collection was conducted using an online questionnaire. The initial measurement (March 2023) and follow-up measurement at the end of the summer semester (June 2023) included established scales for the constructs of forms of motivational regulation (Ryan & Connell, 1989), flow experience (Miller & Dumford, 2016), self-efficacy expectations (Glynn, 2011), and subject-specific or art interest (Ziefle & Jakobs, 2009; Ramm et al., 2012) in STEM subjects. These scales have been tested multiple times (Kröner et al., 2017; Conradty & Bogner, 2018; Glynn et al., 2011; Ruddock et al., 2006) and comprise a total of 36 items (see **Table 1**). In addition to scale reliability (Cronbach's α, **Table 2**), factor analyses were conducted to examine the structure of the instrument. The results of the factor analyses can be found in the appendix in **Table A1** and **Table A2**, including the explanatory information. The items were measured using a 5-point Likert scale. The number and example items of the scales are presented in **Table 1**. The means, standard deviations, and reliabilities of the respective scales are detailed separately for the total sample, the trial group, and the control group in **Table 2**. The correlations between the constructs can be found in **Table A3** in the Appendix. Additionally, data on the prestige of the occupation—coded according to the

International Standard Classification of Occupations (ISCO-08/ESCO; ESCO, 2024) of (a) the mother and (b) the father as well as (c) the pupils' first language (German/non-German)—were collected. For any questions regarding the individual items, trained research staff were available in the classroom. Pupils were also informed about the anonymity and voluntary nature of the survey immediately before completing it.

Table 1. Questionnaire constructs: Overview with example items.

Variable	Example Item	# Items
Language	What language(s) do you speak at home?	1
Father's occupation	What is your father's profession?	1
Mother's occupation	What is your mother's profession?	1
Intrinsic regulation*	I study this subject because I enjoy it.	4
Identified regulation*	I'm studying in this subject so that I can do an apprenticeship later on.	3
Introjected regulation*	I study this subject because I want my teacher to think I am a good student.	3
Extrinsic regulation*	I study in this subject because my parents demand it.	4
Flow*	Time flies when I'm working on a task.	4
Self-efficacy*	I think I have a good grasp of what I learnt in school.	2
STEM interest	I am interested in airplanes/rockets.	8
ART interest	I am interested in music.	5

* "Think about the school subject in which you have the workshop." The questions related to the school subject in which the workshop took place were pointed out directly before the questions related specifically to this subject.

2.4. Analysis

Before the analysis, the data were checked for missing values. Owing to the low number of missing values, Nmissing = 10% - 20% (max. 18.4% for self-efficacy) and a non-significant MCAR test according to Little (χ^2 (2861) = 2668.639, p = .995), imputation was not performed.

Furthermore, the different starting points of the trial and control groups were determined at time t1 via a t-test to determine whether potential differences in the observed changes were due to the intervention or already existed at the start of the study. If there are significant differences between the trial and control groups from the outset, these differences must be considered later when the results are interpreted.

To test the hypotheses, a linear mixed-effects model was estimated for each of the eight motivational constructs. Models 1 - 8 examine the main effects of time (t1 - t2) and art workshops on pupils' respective motivational characteristics, taking into account the school, class, and pupil levels. The primary motive of this study was to test the hypotheses on the interaction terms between time and intervention as well as time, intervention, and covariate (language, parents' occupation), but it was also interesting to consider the main effects. This is because, to correctly interpret the interaction effects, it was important to know whether there was a general trend over time between the trial and control groups.

In Models 1a - 8c, first-order interaction effects (time-intervention, time-covariate, intervention-covariate) and second-order interaction effects (time-intervention-covariate) were estimated. These served to test H1 - H8 and establish whether pupils' first language and their parents' occupation influenced changes in motivational traits. The described models were estimated in RStudio (RStudio Version 2023.06.2+561, version 4.2.2) via the lme ()-function from the "nlme" package (version 3.1.160). The models were estimated using the restricted maximum likelihood (REML) method.

3. Results

3.1. Descriptive Findings

Table 2 presents the sample sizes, means, and Cronbach's alpha coefficients for the pupils' characteristics. The Cronbach's alpha coefficients are generally acceptable to good, except for flow and extrinsic regulation, which have low reliabilities. This limitation should be considered when interpreting the results.

Table 2. Mean values and Cronbach's alpha.

Variable	N_{t1}			N_{t2}			Mean (SD) t_1			Mean (SD) t_2			Cronbach's alpha		
	N_{to}	N_{tr}	N_{co}	N_{to}	N_{tr}	N_{co}	M_{to}	M_{tr}	M_{co}	M_{to}	M_{tr}	M_{co}	α_{to}	α_{tr}	α_{co}
Language	455	235	220	-	-	-	1.58 (.63)	1.57 (.61)	1.60 (.65)	-	-	-	.78	.70	.70
intrinsic regulation	450	231	219	422	225	197	2.25 (1.07)	2.39 (1.03)	2.11 (1.10)	2.31 (1.06)	2.09 (1.06)	2.56 (1.01)	.81	.84	.84
Identified regulation	451	232	219	421	225	196	2.11 (1.21)	1.96 (1.30)	2.26 (1.09)	1.86 (1.25)	1.69 (1.26)	2.05 (1.21)	.81	.88	.88
Introjected regulation	449	230	219	421	225	196	2.06 (1.06)	1.96 (1.07)	2.15 (1.05)	2.02 (1.04)	2.00 (1.05)	2.05 (1.02)	.63	.63	.63
Extrinsic regulation	449	230	219	420	225	195	2.30 (.92)	2.20 (.91)	2.41 (.93)	2.53 (.89)	2.50 (.93)	2.57 (.84)	.52	.59	.59
Flow	447	230	218	418	225	193	2.74 (.85)	2.88 (.78)	2.59 (.89)	2.83 (.73)	2.77 (.73)	2.91 (.73)	.56	.56	.56
Self-efficacy	448	229	219	417	225	192	2.97 (1.05)	3.08 (1.02)	2.86 (1.07)	2.95 (1.11)	3.06 (1.12)	2.82 (1.08)	.72	.72	.72
STEM interest	455	235	220	440	225	215	1.81 (.83)	1.89 (.79)	1.73 (.85)	1.97 (.87)	2.13 (.87)	1.81 (.84)	.79	.78	.78
ART interest	454	235	220	440	225	215	1.85 (1.03)	1.71 (.92)	2.00 (1.11)	1.93 (1.07)	1.86 (1.07)	2.01 (1.07)	.77	.71	.71

Note: to = total sample, tr = trial group, co = control group.

3.2. Difference at Baseline

To assess whether there were pre-existing differences between the trial and control groups in terms of the motivational variables, t-tests were conducted. The means

$\left(\left|\Delta M_{t1}\right| = \left|M_P - M_K\right|\right)$ of the trial group were significantly greater than those of the control group for the scales of interest in STEM ($|\Delta M_{t1}| = .16$, $t(453) = -2.06$, $p < .05$, $d = .82$), flow ($|\Delta M_{t1}| = .28$, $t(446) = -3.593$, $p < .001$, $d = .83$), intrinsic regulation ($|\Delta M_{t1}| = .28$, $t(448) = -2.765$, $p < .05$, $d = 1.06$) and self-efficacy ($|\Delta M_{t1}| = .22$, $t(446) = -2.206$, $p < .05$, $d = 1.05$). The means for art interest ($|\Delta M_{t1}| = .29$, $t(425) = 3.089$, $p < .05$, $d = 1.01$), identified regulation ($|\Delta M_{t1}| = .31$, $t(442) = -2.714$, $p < .05$, $d = 1.20$) and extrinsic regulation ($|\Delta M_{t1}| = .21$, $t(447) = 2.433$, $p < .05$, $d = .92$) were significantly lower in the trial group than in the control group. The difference in introjected regulation approached significance ($|\Delta M_{t1}| = .19$, $t(447) = 1.912$, $p = .056$). In sum, there were statistically significant differences in seven out of eight motivational constructs at baseline. Interpretation of the results from the linear mixed-effects models must account for these baseline differences. This means that the observed effects of the intervention may also be influenced by the differences in initial values.

3.3. Main and Interaction Effects of the Intervention

To determine the influence of context, the respective intraclass correlation values were calculated separately for pupils' motivational characteristics at the various levels (see **Table 3**). The intraclass correlation values are very small at the school and class levels, which means that the difference between the individual schools and classes is relatively small and can be neglected, which is why context effects are rather unlikely. The variance explained at the pupil level, on the other hand, is between 11% and 42%. As expected, the time factor provides the highest variance explained, with 52% to 85%.

Table 3. Intraclass correlation coefficients.

	School	Class	Pupils	Time
STEM interest	3%	4%	36%	57%
ART interest	3%	3%	42%	52%
Flow	3%	1%	11%	85%
Intrinsic regulation	0%	2%	31%	67%
Identified regulation	5%	2%	25%	68%
Introjected regulation	0%	2%	21%	77%
Extrinsic regulation	0%	3%	19%	78%
Self-efficacy	2%	2%	32%	64%

3.3.1. Main Effects

The main effects explain whether the time, group membership, and covariates (pupils' first language, parents' occupation) predict pupils' respective characteristics.

Time: In Model 1, which examines intrinsic regulation, the main effect is significantly positive ($B = .462$, $S.E. = .090$, $p < .001$; **Table 4**; Model 1). This indicates that at the post-test, the pupils had a greater level of intrinsic regulation than at the pre-test. Model 2, which examines identified regulation, the main effect is significantly negative (B = −.304, S.E. = .105, p < .01; Table 4; Model 2). The negative value denotes that pupils' identified regulation decreased slightly over time; this means that the pupils reported a higher level of identified regulation at the time of the pre-test than at the time of the re-test. The models for introjected regulation (Model 3), extrinsic motivation (Model 4), self-efficacy (Model 6) and interest in art (Model 7) do not show a significant main effect of time, i.e. these characteristics did not change significantly between the pre- and post-tests. In the models for flow (B = .282, S.E. = .079, p < .001; Table 4; Model 5) and interest in STEM (B = .151, S.E. = .073, p < .05; Table 4; Model 8), the main effect of time is significantly positive. This indicates that at the post-test, the pupils had a greater level of interest in STEM and flow than at the pre-test.

Intervention: The main effect of the intervention investigated whether there were significant differences in pupils' characteristics between the trial and control groups. This examination was not significant for any of the eight cases. This means that group membership had no effect on the expression of pupils' characteristics.

3.3.2. Interaction Effects

The first-order interaction effects showed whether the change in pupils' characteristics over time was dependent on the intervention or the covariate (pupils' first language, parents' occupation).

Time intervention: This interaction revealed whether the change in pupils' characteristics over time (from the pre-test to the post-test) differed between the trial and control groups.

The changes in the level of self-efficacy and subject-specific interest over the duration of the workshop, as postulated in H6 and H8, depending on group membership, were confirmed taking into account the father's profession in Model 6 (B = .758, S.E. = .281, p < .01; Table 4; Model 6c) and Model 8 (B = .464, S.E. = .184, p < .05; Table 4; Model 8c). Pupils who took part in workshops on integrating art into the classroom presented a significantly greater increase in self-efficacy than those in the control group, and pupils in the trial group expressed greater interest in STEM subjects over time than those in the control group. The changes in the level of extrinsic regulation and art interest over the duration of the workshops, as postulated in H4 and H7 depending on group membership, were confirmed (H4: B = .286, S.E. = .134, p < .05; Table 4; Model 4, H7: B = .271, S.E. = .138, p < .05; Table 4; Model 7). Pupils who took part in workshops on integrating art into the classroom presented a significantly greater increase in extrinsic regulation than those in the control group, and pupils in the trial group expressed greater interest in art over time than those in the control group.

The results for the development of intrinsic regulation (B = −.589, S.E. = .141, p < .001; Table 4; Model 1) and flow experience (B = −.336, S.E. = .125, p < .01; Table 4; Model 5) are significant. However, the negative values of the regression coefficients reject H1 and H5. This means that intrinsic regulation and flow experience increased more strongly among the pupils in the control group than those who took part in the art workshops in STEM lessons. H2 and H3 are not significant; thus, they cannot be confirmed (Table 4; Models 2, 3). This means that for pupils who attended art workshops as part of their STEM lessons, no greater increases in the areas of identified (H2) and introjected (H3) regulation could be observed than for pupils in the control group.

Time intervention covariate: If the interaction of the second order is significant, this indicates that the effect of the workshop on the pupils' characteristics varies depending on the covariate (pupils' first language, parents' occupation). In other words, whether the effect of the intervention over time is different for different levels of the covariate (pupils' first language, parents' occupation) is examined. This study investigated the influence of pupils' first language and parents' occupation on the change in motivational characteristics for all eight hypotheses.

In models 1 - 5 and 7 (Table 4), none of the regression coefficients were significant, indicating that the pupils' first language or parents' occupation did not play a role in the development of pupils' characteristics through the workshops. The models for self-efficacy (B = −.099, S.E. = .048, p < .05; Table 4; Model 6c) and STEM interest (B = −.068, S.E. = .033, p < .05; Table 4; Model 8c) show significant regression coefficients with the father's occupation as a covariate; however, in both cases, the values are negligibly small. This means that the effect of the workshop on pupils' characteristics is independent of the covariate level. The AIC and BIC for the models in Table 4 can be found in the appendix in Table A4.

Table 4. Linear mixed-effects models.

Model	Est.	S.E.	t	p	Est.	S.E.	t	p	Est	S.E.	t	p	Est	S.E.	t	p
Intrinsic regulation	1: main effects				1a: Covariate: Language				1b: Covariate: Job mother				1c: Covariate: Job father			
Intercept	2.242	.130	17.301	.000***	2.227	.282	7.905	.000***	2.152	.167	12.872	.000***	2.117	.181	11.727	.000***
Time	.462	.090	5.136	.000***	.506	.316	1.600	.111	.482	.185	2.601	.010**	.127	.235	.540	.590
Intervention	.058	.159	.368	.720	−.244	.403	−.605	.555	−.002	.209	−.008	.994	.088	.220	.402	.694
Covariate					−.072	.152	−.471	.638	.002	.026	.067	.946	.003	.027	.112	.911
Time + Interv.	−.589	.141	−4.17	.000***	−.858	.453	−1.893	.059	−.701	.223	−3.138	.002**	−.325	.266	−1.222	.223
Time + Cov.					−.012	.184	−.068	.946	−.013	.031	−.434	.664	.039	.036	1.098	.273
Interv. + Cov.					.304	.222	1.367	.172	.055	.035	1.597	.111	.045	.038	1.199	.231
Time + Interv. + Cov.					.044	.258	.171	.865	−.007	.039	−.177	.859	−.075	.046	−1.62	.106
Identified regulation	2: Main effects				2a: Covariate: Language				2b: Covariate: Job mother				2c: Covariate: Job father			
Intercept	2.329	.129	17.985	.000**	2.28	.346	6.591	.000***	2.016	.257	7.843	.000***	1.991	.245	8.129	.000***
Time	−.304	.105	−2.909	.004**	−.521	.380	−1.373	.171	.163	.232	.701	.484	−.214	.294	−.727	.468
Intervention	−.182	.171	−1.059	.312	−.675	.458	−1.473	.163	−.115	.290	−.395	.698	−.024	.263	−.093	.928
Covariate					−.144	.172	−.837	.403	.015	.031	.501	.617	.018	.032	.549	.583

Continued

Time + Interv.	.069	.164	.421	.674	.275	.543	.506	.613	−.438	.279	−1.569	.118	−.114	.332	−.343	.732
Time + Cov.					.159	.221	.720	.472	−.084	.039	−2.175	.030*	−.031	.045	−.701	.484
Interv. + Cov.					.398	.251	1.589	.113	.020	.040	.512	.609	−.005	.045	−.102	.919
Time + Interv. + Cov.					−.184	.310	−.595	.552	.076	.049	1.553	.121	.051	.058	.884	.377
Introjected regulation	3: Main effects				3a: Covariate: Language				3b: Covariate: Job mother				3c: Covariate: Job father			
Intercept	2.153	.079	27.091	.000***	2.088	.262	7.970	.000***	2.307	.160	14.395	.000***	2.243	.174	12.884	.000***
Time	−.129	.099	−1.303	.194	−.230	.348	−.661	.509	.081	.213	.381	.703	.027	.264	.102	.919
Intervention	−.169	.128	−1.323	.213	−.876	.388	−2.258	.040*	−.360	.200	−1.794	.094	−.262	.211	−1.245	.233
Covariate					.040	.151	.263	.793	−.022	.026	−.838	.403	−.005	.027	−.194	.846
Time + Interv.	.139	.155	.897	.370	.806	.499	1.617	.107	.041	.257	.160	.873	−.055	.299	−.184	.854
Time + Cov.					.075	.202	.372	.710	−.048	.035	−1.362	.174	−.042	.040	−1.035	.301
Interv + Cov.					.040	.219	1.826	.069	.023	.034	.686	.493	.004	.038	.114	.910
Time + Interv. + Cov.					−.397	.284	−1.396	.163	.034	.045	.753	.452	.056	.052	1.077	.282
Extrinsic regulation	4: Main effects				4a: Covariate: Language				4b: Covariate: Job mother				4c: Covariate: Job father			
Intercept	2.407	.081	29.878	.000***	2.275	.229	9.937	.000***	2.647	.141	18.772	.000***	2.724	.156	17.493	.000***
Time	.145	.085	1,694	.091	.037	.30	.124	.901	.160	.183	.876	.382	−.053	.227	−.234	.815
Intervention	−.261	.129	−2.024	.068	−.428	.339	−1.263	.227	−.490	.177	−2.769	.015*	−.516	.189	−2.723	.017*
Covariate					.083	.130	.635	.526	−.031	.022	−1.393	.164	−.054	.024	−2.276	.023*
Time + Interv.	.286	.134	2.128	.034*	.651	.430	1.513	.131	.139	.221	.631	.528	.201	.257	.783	.434
Time + Cov.					.074	.175	.424	.672	−.019	.030	−.609	.543	.037	.035	1.061	.289
Interv + Cov.					.116	.190	.613	.540	.042	.029	1.443	.150	.059	.033	1.783	.075
Time + Interv. + Cov.					−.302	.245	−1.23	.219	.020	.039	.531	.596	−.001	.045	−.032	.975
Flow	5: Main effects				5a: Covariate: Language				5b: Covariate: Job mother				5c: Covariate: Job father			
Intercept	2.668	.102	26.05	.000***	2.323	.213	10.888	.000***	2.885	.151	19.075	.000***	2.633	.147	17.882	.000***
Time	.282	.079	3,555	.000***	.601	.273	2.200	.028*	−.019	.165	−.116	.907	.326	.210	1.553	.121
Intervention	.227	.120	1.899	.084	.449	.298	1.507	.154	−.060	.172	−.347	.734	.190	.164	1.161	.265
Covariate					.155	.113	1.375	.170	−.053	.020	−2.68	.008**	−.015	.021	−.723	.470
Time + Interv.	−.336	.125	−2.697	.007**	−.779	.391	−1.992	.047*	−.034	.198	−.170	.865	−.382	.237	−1.612	.108
Time + Cov.					−.181	.159	−1.142	.254	.054	.027	1.967	.050*	−.002	.032	−.056	.955
Interv + Cov.					−.087	.164	−.532	.595	.068	.025	2.661	.008**	.040	.029	1.374	.170
Time + Interv. + Cov.					.228	.223	1.024	.306	−.062	.035	−1.791	.074	−.012	.041	−.299	.765
Self-efficacy	6: Main effects				6a: Covariate: Language				6b: Covariate: Job mother				6c: Covariate: Job father			

Continued

Intercept	2.886	.098	29.427	.000***	2.588	.271	9.550	.000***	3.146	.178	17.723	.000***	3.083	.202	15.242	.000***
Time	−.092	.098	−.932	.352	.325	.328	.991	.322	−.070	.198	−.353	.725	−.691	.25	−2.761	.006**
Intervention	.021	.157	.131	.898	−.107	.401	−.268	.793	−.038	.225	−.169	.868	−.090	.242	−.369	.717
Covariate					.165	.154	1.066	.287	−.049	.027	−1.813	.071	−.040	.028	−1.411	.159
Time + Interv.	.121	.155	.780	.436	−.028	.468	−.059	.953	.074	.237	.311	.756	.758	.281	2.701	.007**
Time + Cov.					−.249	.191	−1.306	.192	−.018	.033	−.553	.580	.079	.038	2.085	.038*
Interv + Cov.					.170	.225	.755	.451	.035	.036	.988	.324	.064	.039	1.63	.104
Time + Interv. + Cov.					.093	.267	.350	.726	.027	.041	.643	.521	−.099	.048	−2.048	.041*
Art interest	7: Main effects				7a: Covariate: Language				7b: Covariate: Job mother				7c: Covariate: Job father			
Intercept	2.07	.147	14.044	.000***	1.671	.276	6.065	.000***	2.087	.190	10.962	.000***	1.964	.182	10.775	.000***
Time	.024	.088	.268	.789	.503	.284	1.770	.077	−.272	.154	−1.768	.078	.001	.179	.005	.996
Intervention	−.353	.185	−1.907	.083	.190	.398	.479	.639	−.365	.230	−1.59	.134	−.343	.224	−1.531	.148
Covariate					.182	.150	1.215	.225	−.025	.026	−.934	.351	.005	.027	.203	.839
Time + Interv.	.271	.138	1.966	.050*	−.065	.406	−.161	.872	.314	.189	1.663	.097	.115	.208	.552	.582
Time + Cov.					−.296	.163	−1.817	.070	.054	.027	2.017	.044*	−.018	.028	−.636	.525
Interv + Cov.					−.258	.218	−1.187	.236	.032	.034	.923	.357	.025	.037	.679	.498
Time + Interv. + Cov.					.129	.23	.563	.574	−.027	.034	−.796	.427	.023	.038	.614	.539
STEM interest	8: Main effects				8a: Covariate: Language				8b: Covariate: Job mother				8c: Covariate: Job father			
Intercept	1.716	.083	2.629	.000***	1.506	.225	6.703	.000***	1.834	.162	11.344	.000***	1.832	.151	12.123	.000***
Time	.151	.073	2.079	.039*	.335	.238	1.406	.161	−.011	.136	−.082	.935	−.105	.158	−.666	.506
Intervention	.221	.132	1,677	.122	.146	.322	.454	.657	−.030	.189	−.161	.875	−.013	.179	−.072	.944
Covariate					.152	.121	1.251	.212	−.007	.021	−.321	.749	−.014	.022	−.664	.507
Time + Interv.	.139	.113	1.226	.221	−.074	.340	−.217	.828	.266	.167	1.592	.112	.464	.184	2.520	.012*
Time + Cov.					−.129	.137	−.943	.346	.026	.024	1.113	.267	.033	.025	1.313	.190
Interv + Cov.					−.015	.176	−.084	.933	.029	.027	1.052	.293	.031	.030	1.500	.294
Time + Interv. + Cov.					.126	.193	.651	.516	−.026	.030	−.854	.394	−.068	.033	−2.052	.041*

Note: ***p < .001, **p < .01, *p < .05, Time: the factor indication pre-test and post-test, Interv. = Intervention: indicates whether the group took part in the workshop or not (trial vs. control group), Cov. = covariate: The covariate that is being controlled in this analysis.

4. Discussion

The aim of this study was to explore how integrating art into regular STEM lessons influences pupils' motivational learning characteristics, including intrinsic, identified, introjected, and extrinsic regulation; flow experience; self-efficacy; interest in art; and subject-specific interest. The intervention involved art workshops designed to foster interdisciplinary connections and enhance motivation. Our analyses yielded mixed results, with significant findings in several key areas.

Consistent with our hypotheses, we found that the intervention significantly increased self-efficacy and subject-specific interest among students in the trial group. These results suggest that the art-based activities, such as visual representations of scientific concepts and dramatizations, helped students engage more deeply with STEM content. The boost in self-efficacy aligns with Bandura's (1986) theory, where mastery experiences foster a sense of competence and achievement. Importantly, our additional analyses confirmed that this effect remained significant even when controlling for socioeconomic background, reinforcing the robustness of the findings.

Beyond self-efficacy and STEM interest, the study also revealed significant increases in pupils' interest in art and extrinsic regulation. This suggests that artistic elements in STEM lessons not only make science more engaging but also cultivate a broader appreciation for the arts. The rise in extrinsic regulation, often associated with external rewards or structured learning environments, may indicate that the workshops provided clear expectations and goals that supported pupil engagement. While extrinsic motivation is sometimes viewed as less desirable than intrinsic motivation, it can serve as a stepping stone toward deeper engagement with a subject.

Contrary to our expectations, intrinsic regulation and flow experience did not show positive changes. In fact, intrinsic regulation decreased more in the trial group. This finding may indicate that some pupils felt overwhelmed or distracted by the additional artistic tasks, possibly because these creative activities introduced complexity to the lessons. A similar trend was observed with flow experience, which could have been disrupted by the ambiguity of the tasks, preventing students from achieving the optimal state of engagement.

These findings can be better understood through a deeper integration of the theoretical frameworks applied in this study. Self-determination theory (Deci & Ryan, 1993) emphasizes the importance of intrinsic motivation in fostering deep learning. The observed decrease in intrinsic regulation suggests that for some students, the introduction of artistic tasks may have interfered with their sense of autonomy or competence, particularly if they were not accustomed to creative activities in a STEM context. The increase in extrinsic regulation further supports this notion, indicating that some students relied more on external structures and incentives rather than internalized motivation. Self-efficacy theory (Bandura, 1986) provides a useful lens for interpreting the increase in students' self-efficacy. The workshops incorporated elements that likely contributed to mastery experiences, such as successfully completing artistic representations of STEM concepts, which reinforced students' confidence in their abilities. Given that self-efficacy plays a crucial role in academic persistence and engagement, this finding underscores the potential of art-based approaches to strengthen students' belief in their STEM competence. Finally, flow theory (Csikszentmihalyi, 1990) offers insights into why flow experience did not increase as anticipated. Flow is most likely to occur when a task is both challenging and well-matched to an individual's skill level. It is possible that the artistic components of the intervention introduced elements of uncertainty or complexity that disrupted students' ability to fully immerse themselves in the learning experience. Future interventions might benefit from structuring artistic tasks in a way that gradually scaffolds students' creative engagement, reducing cognitive overload while maintaining challenge and engagement.

Neither identified nor introjected regulation showed significant changes due to the intervention. One possible explanation is the conceptual overlap between these forms of motivation and both intrinsic and extrinsic regulation. While intrinsic and extrinsic regulation tend to be more clearly distinguishable, identified and introjected regulation exist on a continuum, making their changes more difficult to detect in an educational setting.

A key question in this study was whether the effects of art integration varied by socioeconomic background. The results showed no significant differences, suggesting that the intervention had a comparable effect on pupils from different socioeconomic groups. While this might initially seem unexpected, it can also be interpreted as a strength. The integration of art into STEM lessons appears to be an inclusive teaching approach that engages pupils regardless of their background. However, more nuanced differences might not be captured in quantitative measures alone. Future qualitative analyses, such as interviews with teachers and pupils, could provide deeper insights into how pupils from different backgrounds experience and benefit from these interdisciplinary methods.

The findings suggest that art-based approaches in STEM education can be beneficial if designed carefully. To maximize the positive effects, teachers should ensure that artistic activities are well-integrated into the STEM content rather than being perceived as separate or distracting elements. Providing structured but flexible creative tasks can enhance pupils' engagement while reducing potential cognitive overload. Additionally, teacher training programs should equip educators with strategies to effectively combine artistic and scientific learning, ensuring a meaningful interdisciplinary experience.

From an educational policy perspective, these results emphasize the potential of creative teaching strategies to foster motivation and engagement across diverse pupil populations. Policymakers should consider incorporating structured art-integrated learning approaches into curricula to enhance pupils' self-efficacy, motivation and interest in STEM subjects and art.

This study contributes to the growing field of interdisciplinary education by providing empirical evidence on the motivational effects of art integration in STEM learning. Future research should further explore the mechanisms behind these effects, particularly through qualitative approaches that capture pupils' and teachers' perspectives in greater depth. Additionally, long-term studies are needed to assess whether the observed motivational gains persist over time and how they influence pupils' academic choices. A mixed-methods approach would be particularly valuable in uncovering the deeper cognitive and emotional processes underlying interdisciplinary learning.

5. Limitations

While the study design was robust, some limitations must be considered. Language barriers and inaccurate reporting of socioeconomic status may have influenced results. Additionally, the complexity of the art tasks may have led to unintended distractions for students. A more varied range of artistic forms could also have helped maintain interest and motivation. Furthermore, this study primarily employed a quantitative research design, which is well-suited for identifying general trends and statistical relationships but may not fully reflect the subjective experiences of individual pupils and educators. To complement these findings, qualitative teacher interviews were conducted to gain deeper insights into how arts integration influences social interactions and classroom dynamics. A separate study analyzing these qualitative data is currently in progress. Preliminary findings from the teacher interviews indicate that all educators observed a noticeable increase in pupils' self-efficacy, along with an improvement in classroom atmosphere. Additionally, students displayed non-cognitive learning benefits, such as enhanced concentration, attention, and independent engagement. Notably, students who were typically less vocal in class participated more actively in creative activities, suggesting that role-playing and dramatic elements not only foster creativity but also strengthen social interaction. These qualitative findings highlight the potential of arts integration to influence learning beyond cognitive outcomes, reinforcing the need for future research that combines both quantitative and qualitative perspectives.

Another limitation concerns the standardization of the artistic interventions. While all workshops were designed to align with the STEM curriculum, the specific implementation varied depending on the artistic medium, the expertise of the artists, and the dynamics within different classrooms. This variation may have influenced the consistency of the intervention effects. Future studies should consider a more structured approach to ensure a standardized yet flexible integration of artistic methods. Greater consistency across schools could enhance replicability and provide clearer insights into which artistic strategies are most effective in fostering STEM motivation.

Funding

This study was funded by the Austrian Federal Ministry of Education, Science and Research (BMBWF) and the Austrian Agency for Education and Internationalization (OeAD—Center for Citizen Science) as a Sparkling Science 2.0 Project.

Declarations

Author Contributions: Conceptualization: JL, CH; methodology: JL, CH; soft-

ware: JL, CH; formal analysis: JL; investigation: JL, CH; resources: JL; data curation: JL; writing—original draft preparation: JL; writing—review and editing: JL, CH; supervision: CH; project administration: JL; funding acquisition: CH. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: The data used in this scientific contribution were collected as part of a Sparkling Science 2.0 project, which was approved by the Federal Ministry of Education, Science and Research (BMBWF). As part of the project proposal process, the project, including the planned sample and data collection methods, underwent a thorough review by the relevant authorities. This review comprehensively addressed all ethical aspects of the project, including any reports and contributions arising from it. The study fully complied with Regulation (EU) 2016/679 (General Data Protection Regulation, GDPR) and the ethical standards set forth in the Declaration of Helsinki, ensuring that both institutional and parental consent were secured before the study began.

Informed Consent Statement: The study followed strict ethical protocols to protect the rights and privacy of the participants. Firstly, consent was obtained from all participating pupils and their parents, along with detailed documentation outlining the purpose of the data processing, the roles of the data controllers and the methods of processing. This also included provisions on the treatment of data for scientific research and the rights of participants under the GDPR, in particular the right to access and erasure of personal data under Articles 15 and 17.

Data Availability Statement: To minimize the amount of personal data collected, a pseudonymization process was implemented. All collected data were anonymized and subsequently handled in aggregate form for analysis, ensuring that no individual pupil could be identified from the results. Parents received an Information Notice for Personal Data Processing within Research Projects in accordance with Article 13 of EU GDPR. This document explained the data processing methods and purposes. Parents were asked to provide informed consent, acknowledging that they had read the notice and granting or denying permission for the processing of their child's data for the purposes outlined. They also had the option to authorize the use of their child's images for multimedia materials produced solely for research purposes. The data presented in this study are available on request from the corresponding author. Due to the consent forms signed by the parents, which restrict data availability to ensure the privacy and confidentiality of their children, the data cannot be made fully accessible to the public.

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

Baeten, M., Dochy, F., & Struyven, K. (2013). The Effects of Different Learning Environments on Students' Motivation for Learning and Their Achievement. *British Journal of Educational Psychology, 83,* 484-501. https://doi.org/10.1111/j.2044-8279.2012.02076.x

Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory.* Prentice-Hall.

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2021). At the Dawn of Science, Technology, Engineering, Arts, and Mathematics (STEAM) Education: Prospects, Priorities, Processes, and Problems. *International Journal of Mathematical Education in Science and Technology, 53,* 2919-2955. https://doi.org/10.1080/0020739x.2021.1922943

Boiko, A., Nistor, A., Kudenko, I., & Gras-Velazques, A. (2019). The Attractiveness of Science, Technology, Engineering and Mathematics Subjects. Results from Five Countries. *European Schoolnet.*

Caprille, M., Palmén, R., Sanz, P., & Dente, G. (2015). *Encouraging STEM Studies for the Labor Market.* European Union: Directorate General for Internal Policies.

Catterall, J. S., Dumais, S. A., & Hampden-Thompson, G. (2012). *The Arts and Achievement in At-Risk Youth: Findings from Four Longitudinal Studies (Research Report 55). National Endowment for the Arts.* https://files.eric.ed.gov/fulltext/ED530822.pdf

Connors-Kellgren, A., Parker, C. E., Blustein, D. L., & Barnett, M. (2016). Innovations and Challenges in Project-Based STEM Education: Lessons from ITEST. *Journal of Science Education and Technology, 25,* 825-832. https://doi.org/10.1007/s10956-016-9658-9

Conradty, C., & Bogner, F. X. (2018). From STEM to STEAM: How to Monitor Creativity. *Creativity Research Journal, 30,* 233-240. https://doi.org/10.1080/10400419.2018.1488195

Conradty, C., Sotiriou, S. A., & Bogner, F. X. (2020). How Creativity in STEAM Modules Intervenes with Self-Efficacy and Motivation. *Education Sciences, 10,* Article 70. https://doi.org/10.3390/educsci10030070

Csikszentmihalyi, M. (2000). *Beyond Boredom and Anxiety: Experiencing Flow in Work and Play* (1st ed.). Jossey-Bass.

Deci, E. L., & Ryan, R. M. (1993). The Theory of Self-Determination of Motivation and Its Relevance to Pedagogics. *Zeitschrift für Pädagogik, 39,* 223-238. https://doi.org/10.25656/01:11173

Deci, E. L., & Ryan, R. M. (2008). Self-Determination Theory: A Macrotheory of Human Motivation, Development, and Health. *Canadian Psychology/Psychologie Canadienne, 49,* 182-185. https://doi.org/10.1037/a0012801

DeMoss, K., & Morris, T. (2002). *How Arts Integration Supports Student Learning: Students Shed Light on the Connections.* Chicago Arts Partnerships in Education (CAPE).

Dibiasi, A., Binder, D., Langen, H., Unger, M., & Thaler, B. (2024). *Status Quo und aktuelle Herausforderungen im MINT-Bereich an Hochschulen und am Arbeitsmarkt.* Institute for Advanced Studies. https://irihs.ihs.ac.at/id/eprint/6993/1/ihs-report-2024-dibiasi-binder-et-al-mint-bereich-hochschulen-arbeitsmarkt.pdf

ESCO (2024). *The ESCO Classification. Occupations. ESCO Dataset–v1.2.0.* https://esco.ec.europa.eu/en/classification/occupation?uri=http%3A%2F%2Fdata.europa.eu%2Fesco%2Fisco%2F

European Commission (2023). *Directorate General for Employment, Social Affairs and Inclusion. European Year of Skills: Skills Shortages, Recruitment and Retention Strategies in Small and Medium Sized Enterprises: Report.* Publications Office. https://op.europa.eu/s/z4TM

Fensham, P. J. (2022). The Future Curriculum for School Science: What Can Be Learnt from the Past? *Research in Science Education, 52,* 81-102. https://doi.org/10.1007/s11165-022-10090-6

Glynn, S. M., Brickman, P., Armstrong, N., & Taasoobshirazi, G. (2011). Science Motivation Questionnaire II: Validation with Science Majors and Nonscience Majors. *Journal of Research in Science Teaching, 48,* 1159-1176. https://doi.org/10.1002/tea.20442

Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2017). Co-Measure: Developing an Assessment for Student Collaboration in STEAM Activities. *International Journal of STEM Education, 4,* Article No. 26. https://doi.org/10.1186/s40594-017-0094-z

Hidi, S., Renninger, K. A., & Krapp, A. (2004). Interest, a Motivational Variable that Combines Affective and Cognitive Functioning. In D. Y. Dai, & R. J. Sternberg (Eds.), *Motivation, Emotion, and Cognition* (pp. 470). Routledge. https://doi.org/10.4324/9781410610515

Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on Activities and Their Influence on Students' Interest. *Research in Science Education, 40,* 743-757. https://doi.org/10.1007/s11165-009-9142-0

Howard, J. L., Bureau, J., Guay, F., Chong, J. X. Y., & Ryan, R. M. (2021). Student Motivation and Associated Outcomes: A Meta-Analysis from Self-Determination Theory. *Perspectives on Psychological Science, 16,* 1300-1323. https://doi.org/10.1177/1745691620966789

Hu, L., & Bentler, P. M. (1999). Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria versus New Alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6,* 1-55. https://doi.org/10.1080/10705519909540118

Kröner, J., Goussios, C., Schaitz, C., Streb, J., & Sosic-Vasic, Z. (2017). The Construct Validity of the German Academic Self-Regulation Questionnaire (SRQ-A) within Primary and Secondary School Children. *Frontiers in Psychology, 8,* Article 1032. https://doi.org/10.3389/fpsyg.2017.01032

Lee, B. K., Enciso, P., & Brown, M. R. (2020). The Effect of Drama-Based Pedagogies on K-12 Literacy-Related Outcomes: A Meta-Analysis of 30 Years of Research. *International Journal of Education & the Arts, 21,* No. 30. https://doi.org/10.26209/IJEA21N30

Madison, E., Anderson, R., & Bousselot, T. (2019). Self-Determined to Write: Leveraging Interest, Collaboration, and Self-Direction through a Journalistic Approach. *Reading & Writing Quarterly, 35,* 473-495. https://doi.org/10.1080/10573569.2019.1579127

Meulenbroeks, R., van Rijn, R., & Reijerkerk, M. (2024). Fostering Secondary School Science Students' Intrinsic Motivation by Inquiry-Based Learning. *Research in Science Education, 54,* 339-358. https://doi.org/10.1007/s11165-023-10139-0

Miller, A. L., & Dumford, A. D. (2016). Creative Cognitive Processes in Higher Education. *The Journal of Creative Behavior, 50,* 282-293. https://doi.org/10.1002/jocb.77

OECD (2022). *Education at a Glance 2022: OECD Indicators.* https://doi.org/10.1787/3197152b-en

Ramm, G., Prenzel, M., Baumert, J., Blum, W., Lehmann, R., Leutner, D., Neubrand, M., Pekrun, R., Rolf, H.-G., Rost, J., & Schiefele, U. (2012). *Fragebogenerhebung PISA/I - Internationale Studie (2003) (Skalenkollektion).* Programme for International Student Assessment. https://doi.org/10.7477/15:287:1

Ruddock, G., Clausen-May, T., & Purple, C. (2006). *Validation Study of the PISA 200. PISA 2003 and TIMSS-2003 International Studies of Pupil Attainment (Research Report RR772).* National Foundation for Educational Research.

https://core.ac.uk/download/pdf/4156059.pdf

Ryan, R. M., & Connell, J. P. (1989). Perceived Locus of Causality and Internalization: Examining Reasons for Acting in Two Domains. *Journal of Personality and Social Psychology, 57,* 749-761. https://doi.org/10.1037/0022-3514.57.5.749

Sansone, C., & Smith, J. L. (2000). Interest and Self-Regulation. In *Intrinsic and Extrinsic Motivation* (pp. 341-372). Elsevier. https://doi.org/10.1016/b978-012619070-0/50034-9

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting Self-Regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning. *Research in Science Education, 36,* 111-139. https://doi.org/10.1007/s11165-005-3917-8

Soomro, S. A., Casakin, H., Nanjappan, V., & Georgiev, G. V. (2023). Makerspaces Fostering Creativity: A Systematic Literature Review. *Journal of Science Education and Technology, 32,* 530-548. https://doi.org/10.1007/s10956-023-10041-4

Sung, J., Lee, J. Y., & Chun, H. Y. (2023). Short-term Effects of a Classroom-Based STEAM Program Using Robotic Kits on Children in South Korea. *International Journal of STEM Education, 10,* Article No. 26. https://doi.org/10.1186/s40594-023-00417-8

Toferer, B., Lang, B., & Salchegger, S. (2023). *PISA 2022. Kompetenzen in Mathematik, Lesen und Naturwissenschaft am Ende der Pflichtschulzeit im internationalen Vergleich*. https://doi.org/10.17888/PISA2022-EB

Urhahne, D. (2008). Sieben Arten der Lernmotivation. *Psychologische Rundschau, 59,* 150-166. https://doi.org/10.1026/0033-3042.59.3.150

Ziefle, M., & Jakobs, E. M. (2009). *Wege Zur Technikfaszination (Paths to a Fascination with Technology)*. Springer. https://doi.org/10.1007/978-3-642-04983-5

Appendix

Appendix A1

Given the linguistic adaptation of the instruments to the respective age group, an exploratory factor analysis (EFA) was initially performed to gain insight into the instrument's structure. Both Bartlett's test of sphericity (χ^2 (528) = 4877.4, p < .001) and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO = .830) indicated that the variables were suitable for factor analysis. Consequently, a principal component analysis with Varimax rotation was performed. Although this analysis suggested the presence of nine factors with eigenvalues greater than 1. an eight-factor solution was chosen based on the scree-plot and theoretical considerations. This solution explained 60.26% of the variance and identified eight factors: intrinsic regulation, identified regulation, introjected regulation, extrinsic regulation, flow, self-efficacy, STEM interest, and ART interest. The observed cross-loadings indicated that a few variables loaded onto multiple factors. However, based on theoretical knowledge, this solution was deemed acceptable, as cross-loadings primarily occurred among the regulatory styles. This is not unusual, as extrinsic regulatory styles are often difficult to distinguish clearly. The specific factor loadings are presented in **Table A2** in the Appendix. Subsequently, a confirmatory factor analysis (CFA) was conducted to assess validity. The evaluation of the CFA model fit was based on standard fit indices (Hu & Bentler, 1999). The results of the CFA are provided in **Table A1** in the Appendix.

Table A1. Confirmatory factor analysis (CFA).

Model	χ^2	p	Df	CFI/TLI	RMSEA	SRMR
STEM Interest	208.14	.000	20	.78/.69	.156	.092
ART Interesest	22.53	.000	5	.96/.92	.089	.041
Intrinsic regulation	10.37	.016	2	.99/.96	.094	.024
Identified regulation	Model has only three items					
Introjected regulation	Model has only three items					
Extrinsic regulation	30.62	.000	2	.80/.42	.187	.070
Flow	1.93	2	.38	1.0/1.0	.000	.020
Self-efficacy	Model has only two items					
Model	χ^2	p	Df	CFI/TLI	RMSEA	SRMR
STEM Interest	208.14	.000	20	.78/.69	.156	.092

Appendix A2

The interest in nature shows issues with discriminant validity, as nature is not exclusively a domain of interest for pupils who are enthusiastic about science. Instead, nature holds a universal appeal that is independent of specific scientific interests and is often shared by many children. As a result, it can be challenging to clearly assign this interest to a specific latent factor such as "STEM interest". Similarly, interest in mathematics does not exhibit a clear association with STEM interest. Mathematics as a school subject tends to be highly polarizing, with some pupils finding it fascinating while others perceive it as daunting. Moreover, mathematics can be appreciated or rejected in contexts unrelated to STEM-specific interests (e.g., logic games, everyday experiences), further reducing its discriminant validity. The items related to self-efficacy and flow also display ambiguities, as these constructs are not solely tied to specific domains of activity or interest but are also associated with broader personality traits, such as motivation or engagement. For example, a strong sense of self-efficacy could arise independently of whether the context involves a STEM-related activity or another type of task. Similarly, the experience of flow is often tied to the nature of the activity itself, regardless of its thematic context, making clear assignment more difficult. The issues with discriminant validity among the various styles of extrinsic motivation (e.g., external regulation and introjected regulation) are not surprising. For children, it is often challenging to clearly distinguish between external demands (e.g., rewards or punishments) and internalized expectations (e.g., feelings of guilt or the desire to meet others' expectations). This ambiguity is reflected in the factorial structure of the corresponding items.

Table A2. EFA values.

Item	STEM Interest	ART Interest	Self-eff.	Ident. reg.	Extr. reg.	Intr. reg	Intro. reg.	Flow
I am interested in volcanos.	.769							
I am interested in aeroplanes/rockets.	.743							
I am interested in electrical engineering (electricity).	.725							
I am interested in experiments.	.679							
I am interested in the starry sky.	.662							
I am interested in computer.	.555							
I am interested in nature.	.471							
I am interested in dancing.		.788						
I am interested in theatre/acting.		.722						
I am interested in singing/music.		.719						
I am interested in drawing/painting.		.695						
I am interested in reading.		.488						
I am sure that I understand the subject.			.745					
I believe that I can get an A in the subject.			.721					
When I am working on an assignment. I am fully focused on the task at hand.			.584					
I work and study in this subject because I simply have to learn it.			.566					

Continued

I am interested in Mathematics.	.273					
I work and study in this subject because the knowledge in the subject will help me get a better job later on.		.830				
I work and study in this subject because it will give me more options when choosing a career later on.		.777				
I work and study in this subject so that I can do a certain training later on (e.g., school. apprenticeship or university).		.562				
I work and study in this subject because I would feel guilty if I did little.		.529			.268	
I work and study in this subject because otherwise I would get into trouble with my teacher.			.770			
I work and study in this subject because otherwise I would get pressure at home.			.709			
I work and study in this subject because I want the other pupils to think I'm quite good.			.638			
I work and study in this subject because I want my teacher to think I'm a good student.			.542			
I work and study in this subject because I like thinking about things in the subject.				.682		
I work and study in this subject because I enjoy it.				.653		
I work and study in this subject because I like solving problems in the subject.				.614		
I work and study in this subject because otherwise I would get bad grades.					.745	
I work and study in this subject because I want to learn new things.				.397		
Time passes very quickly when I am working hard.						.469
When I am working hard. I don't like taking breaks.						.768
I usually find work that I enjoy easy.						.526

Note: Intr. reg. = Intrinsic regulation. Ident. reg. = Identified regulation. Intro. reg. = Introjected regulation. Extr. reg. = Extrinsic regulation; Self-eff. = Self-efficacy, Values < .4 have been hidden.

Appendix A3

Table A3. Correlations between the constructs.

	STEM interest	ART interest	Flow	Intr. reg	Ident. reg	Intro. reg	Extr. reg
STEM Int							
ART Int	.231***						
Flow	.201***	.159***					
Intr. reg	.342***	.196***	.449***				
Ident. reg.	.266***	.198***	.293***	.495***			
Intro. reg.	.223***	.103*	.274***	.341***	.396***		
Extr. reg.	.156***	.084	.210***	.261***	.285***	.433***	
Self-efficacy	.193***	.129**	.448***	.459***	.325***	.348***	.239***

Note. Intr. reg. = Intrinsic regulation, Ident. reg. = Identified regulation, Intro. reg. = Introjected regulation, Extr. reg. = Extrinsic regulation; ***p < .001, **p < .01, *p < .05.

Appendix A4

Models 1 - 8 examine the main effects of time (t1 - t2) and art workshops on pupils' respective motivational characteristics, taking into account the school, class, and pupil levels. In Models 1a - 8c, first-order interaction effects (time-intervention, time-covariate, intervention-covariate) and second-order interaction effects (time-intervention-covariate) were estimated. The variables and covariates are shown in Table 4.

Table A4. AIC and BIC for the models in Table 4.

Model	AIC	BIC	Model	AIC	BIC
1	2455.92	2493.65	5	1976.53	2014.22
1a	2425.90	2482.44	5a	1975.08	2031.55
1b	2183.68	2238.96	5b	1779.94	1835.14
1c	2091.57	2146.33	5c	1728.06	1782.74
2	2647.65	2685.39	6	2424.92	2462.60
2a	2657.15	2713.69	6a	2434.84	2491.30
2b	2413.01	2468.29	6b	2196.55	2251.73
2c	2326.07	2380.83	6c	2110.05	2164.71
3	2439.97	2477.69	7	2411.24	2449.19
3a	2446.15	2502.66	7a	2419.32	2476.19
3b	2227.47	2282.72	7b	2182.69	2238.34
3c	2131.87	2186.60	7c	2069.45	2124.60
4	2188.67	2226.37	8	2069.78	2107.73
4a	2199.21	2255.71	8a	2082.09	2138.96
4b	1987.34	2042.57	8b	1891.47	1947.12
4c	1927.15	1981.86	8c	1800.72	1855.87