

## Article

# STEM-Based Curriculum and Creative Thinking in High School Students

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**Abstract:** Creative thinking as a 21st century skill is fundamental to human development and a catalyst for innovation. Researchers frequently study it as it encourages students to analyze, synthesize, and evaluate information from different angles, vital for making informed decisions and solving complex problems. Therefore, this study aimed to assess the impact of a STEM-based curriculum on the development of creative thinking in high school students studying physics. Employing a quasi-experimental design, data were collected from 94 high school students of mixed gender and grade levels using the Torrance Tests of Creative Thinking (TTCT). Data analyses involve multivariate analyses (MANOVA) to answer the research questions. The findings showed that a STEM-based curriculum significantly impacted the development of students' creative thinking compared to students who studied under a traditional curriculum regarding the metrics of fluency, flexibility, and originality. However, the development of participants' metric of elaboration remained the same. Furthermore, the findings showed a significant influence of the grade level of participants who studied under a STEM-based curriculum on the metrics of fluency and elaboration. On the other hand, the findings revealed that grade level did not relate to the STEM-based curriculum for the metrics of flexibility and originality. The findings are discussed in light of recent research on the impact of STEM education.

**Keywords:** stem-based curriculum; creative thinking; high school students; gender difference; Torrance Tests of Creative Thinking



**Citation:** Khalil, R.Y.; Tairab, H.; Qablan, A.; Alarabi, K.; Mansour, Y. STEM-Based Curriculum and Creative Thinking in High School Students. *Educ. Sci.* **2023**, *13*, 1195. <https://doi.org/10.3390/educsci13121195>

Academic Editor: Da Yang Tan

Received: 14 October 2023

Revised: 19 November 2023

Accepted: 21 November 2023

Published: 28 November 2023



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## 1. Introduction

Creative thinking is a 21st century skill that refers to a human's ability to search for solutions, make guesses, formulate hypotheses, and then modify and retest them to communicate such results effectively to others [1,2]. Students should develop the skill of creative thinking throughout their schooling by engaging with a curriculum that enriches them with the tools to solve future problems [3].

STEM-based curricula integrate multiple teaching and learning approaches, such as problem-based learning, adaptation skills to solve real-life problems, and project-based learning, requiring inquiry and technological skills to develop students' creativity [4,5]. Although the multiple STEM-based curricula approaches impact learners' creativity, gender and grade level may also influence the development of learners' creativity after implementing a STEM-based curriculum [6].

On the other hand, studies have shown that a STEM-based curriculum improves students' creative thinking skills through interdisciplinary instruction [7–10]. Creativity is a fundamental aspect of human development. Fostering creativity in education helps students grow intellectually, emotionally, and socially, leading to more well-rounded individuals. Therefore, promoting creativity in education is vital because it equips students with the skills and mindset necessary for success in a rapidly changing world, encourages

personal and cultural enrichment, and fosters innovation and critical thinking, ultimately benefiting individuals and society.

Despite the widespread calls for such curricula, research on their implementation and impact in United Arab Emirates (UAE) schools is limited. While some studies have reviewed STEM-based curricula, they have not directly investigated their impact on UAE students' creative thinking levels. Curriculum implementation has been partial in the past decade [11], and UAE schooling environments are hesitant to adopt STEM-based education [12]. Such hesitance highlights the need for further research studies on the impact of STEM-based curricula on students' creative thinking skills in UAE schools. This study aims to contribute to the existing literature on the influence of STEM-based curricula on developing creative thinking levels in UAE high school students.

Given the scarcity of research studies in the UAE, this study aimed to assess the impact of a STEM-based curriculum on developing creative thinking levels as measured by the metrics of flexibility, elaboration, fluency, and originality while studying physics.

The acknowledgment of a STEM-based curriculum's effectiveness in enhancing students' creative thinking abilities has spurred research and scrutiny in educational systems [12,13]. While some studies have explored the adoption of a STEM-based curriculum in UAE schools and the associated challenges [14], none have directly probed its impact on students' creative thinking. Despite partial implementation [11], the UAE's educational landscape has somewhat hesitated in embracing comprehensive STEM education [12]. This is significant, as STEM education fosters essential 21st century competencies like creative thinking and problem solving. Subpar results in international tests (TIMSS and PISA) have highlighted the need for curricula fostering creativity, critical thinking, and problem solving [15,16]. Some studies stressed the importance of improving STEM-based curricula to bridge the achievement gap in standardized tests [17]. In contrast, others emphasized enhancing students' creative thinking skills for improved performance [18]. Consequently, this study fills a crucial research gap by investigating how implementing a STEM-based curriculum influences the creative thinking levels of high school students in the UAE.

Meanwhile, international studies in various countries, including the United States, Canada, the Middle East, Indonesia, Japan, China, Finland, the United Kingdom, and other European nations, consistently demonstrate the effectiveness of STEM education programs in fostering students' creative thinking skills. Researchers have observed improved creative thinking abilities in students participating in STEM initiatives [19]. Researchers found significant enhancements in creative thinking skills among Indonesian students engaged in STEM programs [20]. Similarly, noticeable improvements in creative thinking resulting from STEM education in Japan, China, and Finland are indicated [21]. These international findings underscore the global impact of STEM education on nurturing students' creative thinking, emphasizing the relevance of studying the influence of a STEM-based curriculum on high school students in the UAE.

While this study has contributed significantly to our understanding of STEM education, it is important to acknowledge several limitations that may affect how the findings are interpreted and generalized. The study's limited scope, focusing on one school and specific curriculum, may restrict the findings' applicability to a broader population. The Torrance Tests of Creative Thinking (TTCT) may only partially capture students' creative thinking intricacies. Subjectivity in test results, influenced by incorrect responses and minimal participant effort, is a concern. Additionally, data collection and analysis in the same term raises questions about results' representativeness over different time frames. These limitations underscore the need for cautious interpretation in the context of STEM education.

## 2. Literature Review

### 2.1. Theoretical Framework

The theoretical framework of this study is based on Piaget's cognitive constructivism theory, which suggests that learners construct knowledge based on their prior knowledge and through self-directed learning [9]. Cognitive constructivism emphasizes student-

centered learning and suggests that teachers act as facilitators rather than primary sources of information [10]. The constructivist approach involves the active participation of students in the knowledge-construction process and fosters motivation, critical thinking, and independent learning [11].

Collaborative learning is a crucial component of the cognitive constructivism theory and is rooted in students working together to debate, reflect, and discuss while learning [12]. This approach enhances learners' depth of knowledge and sensitivity to their environment [13]. The principles of cognitive constructivism theory are closely related to the structure of a STEM-based curriculum, which is based on active knowledge construction by students and collaborative learning activities [5,14].

Both cognitive constructivism theory and STEM education emphasize student-centered learning, allowing learners to develop self-regulation, creativity, and critical thinking while solving complex problems and connecting with real-life scenarios [15]. Infusing STEM education with cognitive constructivism theory can enhance students' innovative competencies by enabling them to apply multidisciplinary knowledge to practical problem-solving [9].

The principles of the cognitive constructivism theory are strongly related to the structure of the STEM-based curriculum. They are based on the active construction of knowledge by students rather than the passive transmission of knowledge by teachers [13]. Furthermore, collaborative learning activities encourage the learners to interact, participate in team activities, and work together toward a common academic goal [14].

Furthermore, both paradigms focus on student-centered learning, allowing learners to be self-regulated, reflective, creative, and critical thinkers while solving complex classroom problems and connecting them to real-life scenarios [11].

## 2.2. Studies on Creative Thinking and STEM

There is no consensus on a definition of STEM education, whether it integrates subjects or is a core subject that applies to other subjects [16]. Diverse perspectives and definitions of STEM education have resulted in more debate. However, there is broad consensus upon the following assertions: Integrated STEM instruction (a) engages students in authentic and meaningful learning using real-world contexts; (b) leverages student-centered pedagogies such as inquiry-based learning and design thinking; and (c) promotes the development of 21st century skills [17]. Despite these areas of agreement, one difficulty persists—the education sector lacks a clear understanding of the role of technology in STEM education projects.

There has been a growing consensus in recent years that creativity and creative thinking are essential educational outcomes on their own or as part of a broader set of competencies dubbed "21st-century skills" [22]. Despite the consensus on the significance of creative thinking, researchers have differing views on how best to define it because of the different schools of thought about creative thinking and how it can be measured [23]. According to a claim by researchers, the definition of creative thinking in academic circles still needs more unity and further investigation [24].

TTCT has gained widespread popularity in innovative research toward the precise definition of creative thinking [25]. The significance of TTCT as a quantitative measure of learners' creative thinking levels was outlined by [26].

Creative thinking is fundamental to 21st century skills because it promotes students' cognitive skills to generate novel ideas and solve problems [27,28]. It was concluded that creative thinking is inherent in human development and personality, evolving from the first year of schooling and continuing through higher education [24]. As a result, creative thinking should be developed by preparing learning environments that influence the number of experiences that young learners have in their core classes.

Collectively, the research underscores the positive impact of STEM-based education on fostering creative thinking, problem-solving skills, critical thinking, mental flexibility, and practical application [15,29,30]. Additionally, researchers have shown that STEM education can positively impact students' cognitive flexibility and self-exploration, regardless of

their grade level [31]. This body of work aligns with the principles of STEM education, as emphasized by [32], promoting critical thinking, innovation, and creativity across diverse educational contexts. Simultaneously, exploring the impact of STEM experiences on grade 10 students, researchers found significant effects on their environmental awareness, influencing their learning attitudes, motivation, and adaptive thinking abilities [33]. In a related context, researchers attributed this difference to their heightened curiosity for the unknown by observing that grade 10 students surpassed their grade 12 counterparts in the flexibility metric of the Torrance Tests of Creative Thinking (TTCT) [34].

In contrast, researchers have explored the development of cognitive flexibility in high school students enrolled in STEM education programs [35]. Surprisingly, their findings indicated a need for more substantial improvement in cognitive flexibility over the high school years, possibly due to preexisting knowledge and motivation factors outweighing the curriculum's impact. Likewise, researchers compared the originality of high school students enrolled in STEM education and found limited improvement [36]. This finding suggests that individual factors play a more significant role in originality than the specific curriculum used in STEM education. In behavioral investigations, differences in creativity based on gender have been extensively investigated. Previous research has given evidence of the impact of gender on levels of creativity [37].

Moreover, a study showed how males and females may differ in creativity due to differences associated with biological influences on gender [38]. Females scored better than males in TTCT due to their greater interest in discovering new knowledge [39]. Similarly, females scored higher than males in the total TTCT score and the subtests of fluency and flexibility; males scored higher on the originality subtest [40].

Conversely, while meta-analysis on gender differences in creativity concluded that there were no significant gender disparities in creative abilities across the general population [41], it became clear when examining children's divergent thinking, a facet of creative thinking, that the influence of gender diminishes in significance [42], in addition, the study emphasized the role of age and parental education in shaping gender-related variations in creative thinking among children.

Creativity leads to developing novel ideas, views, concepts, principles, and products in society [43]. Creativity must first be encouraged in students if it is to be demonstrated later in life. Several forms of creativity have been discussed previously, including creative thinking, creative writing, and creative arts [43,44]. Students must be taught and supported in communicating and expressing these concepts appropriately later in life. Students' grade level might affect their creative thinking because of a steady increase in their ability to think in a detailed and reflective manner [45]. That the creativity of ideas and imagination could be significantly improved when students experience multiple learning scenarios as they move from one grade level to another is emphasized in the work by researchers [46,47].

### *2.3. Studies on STEM-Based Curriculum Implementation in the UAE*

Implementing STEM learning has developed students' problem-solving skills and enhanced entrepreneurship skills [48]. Additionally, STEM educators have advocated for incorporating entrepreneurship skills and practices in teaching pedagogies. According to educators, such pedagogy will increase student competency strategies. The study by [3] identifies the UAE as a nation that has effectively integrated STEM education into its curriculum. As a result, STEM curriculum teachers are experienced and professional, representing project-based learning by adding an activity every month. Further, engineering-based learning, compared to other disciplines, is significantly underrepresented and needs collaboration and an interdisciplinary approach.

An integrated and holistic approach is needed to implement and execute STEM curricula in UAE education. The challenges and hurdles must be addressed, and STEM implementers and educators must provide reasonable solutions for successfully implementing STEM curricula at all educational levels in the UAE [14]. To encourage the development of positive attitudes toward STEM, students must be provided with an opportunity to

experience the multidisciplinary nature of STEM in order to enhance their preparation for STEM job fields. Due to the challenges and barriers limiting such implementation, the UAE educational system only partially implements the STEM-based curriculum.

### 3. Methodology

#### 3.1. Context of the Study

This study was conducted in one private K12 school implementing STEM-based and American Common Core curricula. This school can be described as a large school; it has six campuses—two located in Abu Dhabi and the rest in Al Ain, Sharjah, Ras Al Khaimah, and, recently, Dubai. The selected school was established in 2006 in Al Ain, with 2622 students allocated to mixed-gender classes from kindergarten (KG) to primary. Then, it separated as single-gender only and offered an IB curriculum for its KG, primary years, middle years, and diploma years program. The IB curriculum is a STEM-based curriculum based on a project- and inquiry-based framework. In addition, the school offers an American curriculum based on Common Core standards in English, math, and science. The study was conducted in Term One of the 2021–2022 academic year within four teaching weeks. Al Ain campus was selected as the study location because it is the only authorized IB school in Al Ain city.

#### 3.2. Research Design

This study was designed as a quasi-experimental quantitative research method to assess the impact of STEM-based curriculum as an independent variable on the development of creative thinking levels of high school students. Other independent variables, namely, gender (male/female) and grade level (grade 10/grade 12) were also investigated for their influence on the participants' creative thinking levels before and after the intervention. As part of the quasi-experimental design, the participants ( $n = 94$ ) were divided into experimental and control groups.

#### 3.3. Participants and Sampling

The study participants were high school students from grades 10 and 12 from various backgrounds and nationalities in Al Ain, UAE, aged between 16 and 18 years old; 70% of the sample were Emirati nationals and 30% were expatriates. As presented on Table 1, the sample comprised 94 participants selected by the stratified random sampling technique to ensure that gender and grade levels were represented. They were divided into eight sections, four for each grade level. Following the stratification, the four sections were randomly assigned to experimental (two male and two female classes) and control groups. The experimental group studied physics under the STEM-based curriculum, while the control group studied physics under the traditional curriculum.

**Table 1.** Summary of Characteristics of Participants.

Group	N	Gender		Grade Level	
		Male	Female	Ten	Twelve
Experimental	48	20	28	22	26
Control	46	21	25	24	22
Total	94	41	53	46	48

#### 3.4. STEM-Based Learning Activities

The learning activities of the present study were based on the IB curriculum, a STEM-based curriculum that aims to develop the twenty-first century skills found in STEM. Teaching and learning activities were based on hands-on and mind-on activities using project-based and problem-based approaches. The IB curriculum features STEM activities where students utilize STEM-related skills to engage in learning and solve problems

identified in the teacher's lesson plan (see Appendix A). The methods adopted in implementing the STEM approach included project-based and problem-based activities that connect STEM subjects. For example, STEM activities for Grade 10 lasted for four weeks. They included challenges related to the topic "Force and Motion," in which students learn basic concepts related to force and motion (core scientific concepts) before engaging in a simulator challenge that requires manipulation of forces and changes in motion to simulate a crash and observe and identify motion before and after the simulated crash (technology). Furthermore, students can calculate and measure forces/net force/acceleration and prototype their task using 3D modeling software (mathematics and engineering).

### 3.5. Instrument

The Torrance Tests of Creative Thinking (TTCT) was the main instrument used in the current study. TTCT has been a widely used test for measuring creativity since its development in the 1960s [49,50]. The original version of the Torrance Test, known as the Figural TTCT (see Appendix B), was used in the study, with some modifications to match the content of the study. The test has undergone several revisions and updates to enhance its reliability and validity. The construct validity of the TTCT content was assessed by obtaining expert opinions from a panel of professionals, including two educational professors with degrees in STEM education.

The reliability coefficient of the test was calculated using a sample of 60 students (30 students from Grade 10 and 30 students from Grade 12) not included in this study sample. An alpha coefficient of 0.80 was obtained; thus, the test was regarded as reliable for the current study. The calculated Cronbach's  $\alpha$  values indicated that TTCT's four metrics of fluency, elaboration, flexibility, and originality were 0.86, 0.818, 0.736, and 0.536, respectively. Based on these reported alpha values, the test was deemed to have adequate internal consistency.

### 3.6. Data Analysis

The Statistical Package for Social Sciences software (SPSS) Package 28 was used to analyze the collected data. The analysis included descriptive statistics, namely mean (M), standard deviation (SD), and inferential statistics using several multivariate analyses (MANOVAs) to answer the research questions about how much impact a STEM-based curriculum and the gender and grade levels of participants might have on the development of students' creative thinking levels (fluency, elaboration, flexibility, and originality), treated as separate dependent variables.

In order to make sure that the collected data met the critical assumptions of the employed statistical analyses, the properties of the collected data were evaluated for compliance with various statistical assumptions needed to perform the analyses.

## 4. Findings

### *STEM-Based Education and Creative Thinking*

The four TTCT metrics (fluency, elaboration, flexibility, and originality) served as dependent variables in a multivariate analysis of variance (MANOVA), with the instruction method serving as an independent variable with two levels (STEM-based and non-STEM-based). The means and standard deviations for each dependent variable across groups and grades are in Tables 2 and 3.

**Table 2.** Group-Specific Descriptive Statistics for Measures of Torrance Test Subscales.

Group	Fluency		Elaboration		Flexibility		Originality	
	M	SD	M	SD	M	SD	M	SD
Experimental	1.202	1.003	1.312	0.839	1.586	0.2	1.185	1.054
Control	0.861	1.027	1.072	0.989	1.288	1.079	1.062	1.009

**Table 3.** Descriptive Statistics for Measures of Torrance Test Subscales Stratified by Grade Level.

Group		Fluency		Elaboration		Flexibility		Originality	
		M	SD	M	SD	M	SD	M	SD
Grade 10	Pre	1.128	1.015	1.122	0.890	1.882	1.221	0.921	0.969
	Post	1.907	1.099	2.660	1.004	5.636	1.109	3.083	1.459
Grade 12	Pre	0.945	1.036	1.265	0.949	5.340	1.369	1.320	1.056
	Post	2.453	1.199	2.061	0.871	1.534	0.127	3.944	1.782

It was crucial to check the data for adherence to the MANOVA assumptions before commencing the analysis. The study design ensures that participants are guaranteed to be independent of each other. Also, the measurement types for fluency, elaboration, flexibility, and originality are continuous. In addition, data met the assumption of having a proper sample size.

Regarding normality, the Kolmogorov–Smirnov test result was used to test the normal data distribution. Since the test result was significant ( $p > 0.05$ ) for each variable (see Table 4), the data are normally distributed.

**Table 4.** Normality Test for Torrance Test’s Subscales.

	Kolmogorov-Smirnov		
	Statistic	Df	Sig.
Fluency Pre	0.061	94	0.200 *
Fluency Post	0.065	94	0.200 *
Elaboration Pre	0.059	94	0.200 *
Elaboration Post	0.061	94	0.200 *
Flexibility Pre	0.078	94	0.200 *
Flexibility Post	0.037	94	0.200 *
Originality Pre	0.067	94	0.200 *
Originality Post	0.080	94	0.174
Whole test Pre	0.055	94	0.200 *
Whole test Post	0.040	94	0.200 *

\* Significance levels.

The homogeneity of variance and covariance assumption was tested using Box’s test of equality of covariance matrices. The test revealed unequal variance–covariance matrices of the dependent variables across levels of treatment, indicating that the homogeneity assumption was tenable, and it did not yield a significant result at the  $p > 0.05$  level (Box’s  $M = 12.026$ ,  $p = 0.323 > 0.05$ ; see Table 5).

**Table 5.** Box’s M Test of Equality of Covariance Matrices for the Two Groups.

Box’s M	12.026
F	1.146
df1	10
df2	40,293.040
Sig.	0.323

Bartlett’s sphericity test results were significant (approximate chi-squared  $\chi^2 = 465.252$ ,  $p = 0.000 < 0.001$ ), as shown in Table 6. This indicated that the correlation between the dependent measures was sufficient to continue the analysis.

**Table 6.** Bartlett's Test of Sphericity for the Dependent Variables.

<b>Likelihood Ratio</b>	<b>0.000</b>
Approx. Chi-Square	465.252
Df	15
Sig.	0.000

The current data had no extreme scores, outliers, or violations of statistical assumptions observed. As a result, these data met MANOVA statistical assumptions.

Table 7 shows the MANOVA results. At the  $p < 0.05$  level, Pillai's trace = 0.119,  $F(4, 85) = 2.872$ , and  $p = 0.028 < 0.05$ , meaning that treatment significantly affected the development of creative thinking at all four levels. For these tests, the effect size for this association is  $\eta^2 = 0.119$ . The results indicated statistically significant differences between the four treatment groups on the perceived level of creative thinking. Likewise, the MANOVA results showed that grade level significantly influenced creative thinking at all four levels at the  $p < 0.05$  level (Pillai's trace = 0.127,  $F(4, 85) = 3.104$ ,  $p = 0.020 < 0.05$ ). This relationship's partial  $\eta^2$  effect size was 0.127. Accordingly, it was concluded that there were statistically significant differences in students' creative thinking across the four metrics (fluency, elaboration, flexibility, and originality) and grades. Furthermore, the MANOVA results revealed that student gender had no significant impact on the measures of creative thinking. The treatment  $\times$  grade multivariate interaction effect was likewise statistically significant, with Pillai's trace = 0.104,  $F(4,85) = 3.135$ ,  $p = 0.023 < 0.05$ , and partial  $\eta^2 = 0.104$ .

**Table 7.** Post-test Two-way MANOVA for Groups, Gender, and Student Grades.

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared ( $\eta^2$ )
Intercept	Pillai's trace	0.958	480.750 <sup>a</sup>	4.000	85.00	<0.001	0.958
	Wilks' lambda	0.042	480.750 <sup>a</sup>	4.000	85.00	<0.001	0.958
	Hotelling's trace	22.624	480.750 <sup>a</sup>	4.000	85.00	<0.001	0.958
	Roy's largest root	22.624	480.750 <sup>a</sup>	4.000	85.00	<0.001	0.958
Groups	Pillai's trace	0.119	2.872	4.000	85.00	0.028	0.119
	Wilks' lambda	0.881	2.872	4.000	85.00	0.028	0.119
	Hotelling's trace	0.135	2.872	4.000	85.00	0.028	0.119
	Roy's largest root	0.135	2.872	4.000	85.00	0.028	0.119
Grade Level	Pillai's trace	0.127	3.104 <sup>a</sup>	4.000	85.00	0.020	0.127
	Wilks' lambda	0.873	3.104 <sup>a</sup>	4.000	85.00	0.020	0.127
	Hotelling's trace	0.146	3.104 <sup>a</sup>	4.000	85.00	0.020	0.127
	Roy's largest root	0.146	3.104 <sup>a</sup>	4.000	85.00	0.020	0.127
Gender	Pillai's trace	0.037	0.825 <sup>a</sup>	4.000	85.00	0.513	0.037
	Wilks' lambda	0.963	0.825 <sup>a</sup>	4.000	85.00	0.513	0.037
	Hotelling's trace	0.039	0.825 <sup>a</sup>	4.000	85.00	0.513	0.037
	Roy's largest root	0.039	0.825 <sup>a</sup>	4.000	85.00	0.513	0.037
Groups $\times$ Grade Level	Pillai's trace	0.104	3.135 <sup>a</sup>	4.000	85.00	0.023	0.104
	Wilks' lambda	0.893	3.135 <sup>a</sup>	4.000	85.00	0.023	0.104
	Hotelling's trace	0.120	3.135 <sup>a</sup>	4.000	85.00	0.023	0.104
	Roy's largest root	0.120	3.135 <sup>a</sup>	4.000	85.00	0.023	0.104

Table 7. Cont.

Effect	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared ( $\eta^2$ )
Groups $\times$ Gender	Pillai's trace	0.000	. <sup>a</sup>	0.000	0.000	.
	Wilks' lambda	1.000	. <sup>a</sup>	0.000	86.50	.
	Hotelling's trace	0.000	. <sup>a</sup>	0.000	2.000	.
	Roy's largest root	0.000	0.000 <sup>a</sup>	4.000	84.00	1.000

<sup>a</sup> Exact Statistic.

To determine whether there were significant differences in the categories of creative thinking (fluency, elaboration, flexibility, and originality) between student groups (experimental and control) and student grades (10 and 12), an examination was conducted to explore the various categories of creative thinking. A two-way multivariate analysis of variance (MANOVA) was conducted to examine the potential interaction effects between two levels of the first independent variable, namely "groups" (1) STEM-based instruction and (2) non-STEM-based instruction, and two levels of the other independent variable, namely "grades" (1) Grade 10 and (2) Grade 12, on four dependent variables: flexibility, elaboration, fluency, and originality.

Table 8 shows that the results of the experimental and control groups of students on the fluency test are statistically different.  $F(1, 5.021) = 5.021, p = 0.048$  partial  $\eta^2 = 0.041$ ; flexibility,  $F(1, 6.771) = 6.771, p = 0.013$ , partial  $\eta^2 = 0.065$ ; and originality,  $F(1, 124.552) = 124.552, p = 0.001$ , partial  $\eta^2 = 0.508$ . However, there is no significant difference regarding elaboration since  $p = 0.129 > 0.05$ .

On the other hand, Table 8 shows that students in grades 10 and 12 scored significantly differently on the fluency test,  $F(1, 7.769) = 7.769, p = 0.016$ , partial  $\eta^2 = 0.062$ ; elaboration,  $F(1, 8.932) = 8.932, p = 0.002$ , partial  $\eta^2 = 0.102$ ; and originality  $F(1, 11.950) = 11.950, p = 0.003$ , partial  $\eta^2 = 0.090$ . However, the two groups had no statistically significant difference regarding flexibility ratings,  $F(1, 3.410) = 3.410, p = 0.077$ , partial  $\eta^2 = 0.034$ . Table 9 displays the significant differences between the groups, as well as the results of the post-hoc comparison test.

Table 9 shows the post-hoc analysis using Bonferroni for multiple comparisons. A statistically significant difference was found between STEM-based and non-STEM-based groups ( $p = 0.05$ ) for fluency. Analysis of the mean results revealed that in terms of fluency, students in the STEM-based group (mean = 1.202, SD = 1.003) scored significantly higher than students in the non-STEM-based group (mean = 0.861, SD = 1.027). Regarding flexibility, students in the STEM-based group rated significantly higher (mean = 1.586, SD = 0.209) than students in the non-STEM-based group (mean = 1.288, SD = 1.079) at  $p = 0.05$ . Regarding originality, students in the STEM-based group rated significantly higher (mean = 1.185, SD = 1.054) than students in the non-STEM-based group (mean = 1.062, SD = 1.009) at  $p = 0.05$ .

Table 10's post-hoc analysis was conducted utilizing Bonferroni for multiple comparisons. There was a statistically significant difference in fluency between students in grades 10 and 12 ( $p = 0.016$ ). Analysis of the mean results revealed that in terms of fluency, grade 12 students rated significantly higher (mean = 2.453, SD = 1.199) than grade 10 students (mean = 1.907, SD = 1.099) at  $p = 0.05$ , whereas for elaboration, grade 10 students rated significantly higher (mean = 2.660, SD = 1.004) than grade 12 students (mean = 2.061, SD = 0.871) at  $p = 0.05$ . On the other hand, for originality, grade 12 students rated significantly higher (mean = 3.944, SD = 1.782) than grade 10 students (mean = 3.083, SD = 1.459) at  $p = 0.05$ .

**Table 8.** Groups and Grades Two-way MANOVA for Torrance Test Subscale.

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared ( $\eta^2$ )
Intercept	Fluency	448.435	1	448.435	349.010	<0.001	0.793
	Elaboration	522.274	1	522.274	601.448	<0.001	0.869
	Flexibility	272.466	1	272.466	255.937	<0.001	0.738
	Originality	1144.502	1	1144.502	862.544	<0.001	0.905
Groups	Fluency	5.021	1	5.021	3.908	0.048	0.041
	Elaboration	2.041	1	2.041	2.350	0.129	0.025
	Flexibility	6.771	1	6.771	6.360	0.013	0.065
	Originality	124.552	1	124.552	93.867	<0.001	0.508
Grade Level	Fluency	7.769	1	7.769	6.046	0.016	0.062
	Elaboration	8.932	1	8.932	10.286	0.002	0.102
	Flexibility	3.410	1	3.410	3.203	0.077	0.034
	Originality	11.950	1	11.950	9.006	0.003	0.090
Groups × Grade Level	Fluency	0.000	1	2.301	2.301	0.000	0.991
	Elaboration	0.002	1	3.002	3.002	0.003	0.958
	Flexibility	0.168	1	5.168	5.168	0.170	0.681
	Originality	0.229	1	3.229	3.229	0.181	0.671
Error	Fluency	116.924	91	1.285			
	Elaboration	79.021	91	0.868			
	Flexibility	96.877	91	1.065			
	Originality	120.747	91	1.327			
Total	Fluency	578.282	94				
	Elaboration	610.693	94				
	Flexibility	379.718	94				
	Originality	1429.385	94				
Corrected Total	Fluency	128.970	93				
	Elaboration	89.494	93				
	Flexibility	106.488	93				
	Originality	262.713	93				

Finally, differences in multivariate interaction effects of groups × grade level on fluency scores are shown in Table 8 ( $F(1, 2.301) = 2.301, p = 0.000, \text{partial } \eta^2 = 0.991$ ) as well as elaboration ( $F(1, 3.002) = 3.002, p = 0.026, \text{partial } \eta^2 = 0.958$ ). However, no significant differences were observed among groups and gender regarding their scores on both flexibility ( $F(1, 5.168) = 5.168, p = 0.170$ ) and originality ( $F(1, 3.229) = 3.229, p = 0.181$ ). This means that for any student in either grade 10 or grade 12 receiving STEM-based instruction, their creative thinking increased more relative to the non-STEM-based group in fluency and elaboration. However, STEM-based instruction did not affect students' creative thinking regarding flexibility and originality in either grade.

**Table 9.** Post-test Post-hoc Tests Based on Torrance Test Subscale and Student Groups.

Dependent Variable	(I) Groups	(J) Groups	Mean Difference (I–J)	Std. Error	Sig. <sup>a</sup>	95% Confidence Interval for Differences	
						Lower Bound	Upper Bound
Fluency	STEM-based	Non-STEM-based	−0.463 *	0.234	0.048	−0.929	0.002
	STEM-based	Non-STEM-based	0.463 *	0.234	0.048	−0.002	0.929
Elaboration	STEM-based	Non-STEM-based	0.295	0.193	0.129	−0.087	0.678
	STEM-based	Non-STEM-based	−0.0295	0.193	0.129	−0.678	0.087
Flexibility	STEM-based	Non-STEM-based	0.538 *	0.213	0.013	0.114	0.962
	STEM-based	Non-STEM-based	−0.538 *	0.213	0.013	−0.962	−0.114
Originality	STEM-based	Non-STEM-based	2.307 *	0.238	<0.001	1.834	2.780
	STEM-based	Non-STEM-based	−2.307 *	0.238	<0.001	−2.780	−1.834

<sup>a</sup> the *p*-value is less than 0.05, \* The differences are significance.

**Table 10.** Post-test Post-hoc Tests Based on Torrance Test Subscale and Student Grades.

Dependent Variable	(I) Groups	(J) Groups	Mean Difference (I–J)	Std. Error	Sig. <sup>a</sup>	95% Confidence Interval for Differences	
						Lower Bound	Upper Bound
Fluency	Grade 10	Grade 12	−0.576 *	0.234	0.016	−1.042	−0.111
	Grade 10	Grade 12	0.576 *	0.234	0.016	0.111	1.042
Elaboration	Grade 10	Grade 12	0.618 *	0.193	0.002	0.235	1.001
	Grade 10	Grade 12	−0.618 *	0.193	0.002	−1.001	−0.235
Flexibility	Grade 10	Grade 12	0.382	0.213	0.077	−0.042	0.806
	Grade 10	Grade 12	−0.382	0.213	0.077	−0.806	0.042
Originality	Grade 10	Grade 12	−0.715 *	0.238	0.003	−1.188	−0.242
	Grade 10	Grade 12	0.715 *	0.238	0.003	0.242	1.188

<sup>a</sup> the *p*-value is less than 0.05, \* The differences are significance.

## 5. Discussion

With an effect size of  $\eta^2 = 0.119$ , the results demonstrated significant differences in creative thinking as assessed by the four metrics of TTCT for the various treatment groups of STEM-based students. Overall, the results revealed statistically significant differences in the student groups' scores for fluency (experimental and control),  $F(1, 5.021) = 5.021$ ,  $p = 0.048$  partial  $\eta^2 = 0.041$ ; flexibility,  $F(1, 6.771) = 6.771$ ,  $p = 0.013$ , partial  $\eta^2 = 0.065$ ; and originality,  $F(1, 124.552) = 124.552$ ,  $p = 0.000$ , partial  $\eta^2 = 0.508$ . However, there was no significant difference regarding elaboration since  $p = 0.129 > 0.05$ .

Such findings are reported by [51], who concluded that implementing STEM as an interdisciplinary unit enhanced students' cognitive skills and creativity as measured by TTCT and its metrics through analysis and problem-solving techniques to create complex projects. Furthermore, using an integrated approach to teaching STEM impacted students' creative thinking [52]. By enabling learners to use their prior knowledge to analyze, evaluate, and create novel products, their performance in TTCT improved. Using the latest technologies may shape the participating students' mental experiences, analysis, and problem-solving competencies, which are inputs of creative thinking and may have caused such results on the TTCT for the experimental group after STEM intervention.

Furthermore, the implemented STEM pedagogies of inquiry and project engagement offer an in-depth understanding of STEM concepts and encourage practical application

through exploration and practice, which enhances critical thinking and fluency of ideas [53]. Similarly, using trial-and-error practices while creating STEM projects nurtures the growth of students' mindsets through prototyping, computer modeling, and simulation, impacting their mental flexibility and language fluency skills, reflected in high-quality TTCT outcomes [30]. Furthermore, inquiry-based learning within STEM classes positively impacts the development of students' creativity due to working with learning scenarios related to real-life implications that enhance curiosity, flexibility, and character building [15]. Although the results showed a significant impact of a STEM-based curriculum on creative thinking metrics related to fluency, flexibility, and originality, no statistically significant impact of STEM education on the metric of elaboration was observed.

The significant impact of a STEM-based curriculum on fluency, flexibility, and originality indicates that students exposed to STEM education demonstrate enhanced abilities in generating a large number of ideas (fluency), thinking divergently and considering multiple perspectives (flexibility), and producing novel and unique ideas (originality). STEM education emphasizes critical thinking, problem solving, and innovation.

The positive effect of STEM education on fluency can be attributed to the nature of STEM subjects, which often require students to brainstorm and generate a wide range of ideas to tackle complex problems. Hands-on activities, peer collaboration, and experimentation may help STEM fluency. The increased flexibility reported among students exposed to STEM education reflects their ability to look beyond standard methods and explore multiple views. STEM subjects inspire open-ended inquiry, experimentation, and problem solving. This fosters cognitive flexibility and adaptability, allowing students to approach challenges from various angles and generate innovative solutions. The significant impact of STEM education on originality suggests that exposure to STEM subjects nurtures students' ability to think creatively and produce unique ideas. Project-based STEM education encourages students to solve real-world challenges creatively. Inquiry-based learning and technology, engineering, and design principles may foster creative thinking. However, STEM education may not improve students' ability to elaborate, add details, or explain complex concepts. Elaboration is a fundamental component of creative thinking, as it entails extending and expanding ideas to give comprehensive and detailed answers. Future studies should explore ways within STEM education to target the development of elaboration abilities in order to increase creative thinking results further. These findings align with previous research that has demonstrated the positive effects of STEM education on various cognitive skills, problem-solving abilities, and innovative thinking. For example, students engaged in a STEM-based curriculum exhibited higher creative thinking and problem-solving levels than those in traditional educational settings [54]. The findings are also consistent with the principles of the STEM education movement, which emphasizes the integration of science, technology, engineering, and mathematics to foster critical thinking, innovation, and creativity [31].

The results showed a significant effect of the grade level of participants who studied under a STEM-based curriculum on fluency and elaboration metrics of creativity.

Researchers have found that creative thinking increases by grade level due to experiences across the lifespan; STEM experience develops the cognitive fluency of learners toward complex situations [55]. Similarly, STEM learning experiences affect high school students' performance in the subset of cognitive elaboration due to self-exploration and reflection on real-life situations [56]. Meanwhile, the STEM experience influences students' sensitivity to the surrounding environment, impacting their attitudes to learning, motivation, and mental abilities to shift ideas [32]. Similarly, STEM-based classes provide students with a higher curiosity in discovering the unknown along their school journey than students who studied under the traditional curriculum [34]. On the other hand, the results showed no significant effect of the grade level of participants who studied under a STEM-based curriculum on the flexibility and originality metrics of creativity.

In addition, the development of flexibility in a longitudinal study spanning high school students after implementing STEM education was explored by [35]. The findings

indicated no significant improvement in cognitive flexibility across the high school years. This could be due to students' prior knowledge or motivation, which overshadowed the impact of the implemented curriculum.

A comparative analysis of the originality and uniqueness of ideas among high school students who studied STEM education was conducted [36]. The results revealed that there needed to be more originality for those who studied under a STEM-based curriculum. This result may be attributed to the individual differences of participants regardless of their grade level, which may have more potent influences on the skill of originality than the specific curriculum.

On the other hand, there was no statistically significant difference between the two genders after STEM intervention on any of the four measures of creative thinking. Gender had no significant impact on creative thinking regardless of the implemented curriculum; if curricula are designed and implemented without gender bias, students of all genders can thrive and perform equally well [42]. By creating an inclusive and supportive learning environment that challenges and values creativity in all students, gender disparities in creative thinking performance can be minimized [45,57]. Similarly, societal and cultural factors, including stereotypes, expectations, and biases, can influence gender differences in creative thinking [29]. These factors can affect opportunities, confidence, and self-perception, potentially impacting creative thinking outcomes regardless of any curriculum implemented in classrooms.

## 6. Recommendations

To better expand upon this study, the following recommendations are suggested:

1. A STEM-based curriculum needs to be implemented from elementary to high school because the early implementation of STEM-based curricula sharpens students' creative thinking skills and broadens their interest in careers in STEM, increasing the pool of people considering careers in STEM fields who can contribute to research, development, and innovation.
2. Future research must focus on developing curriculum materials and instructional models for STEM integration that are primarily concerned with developing students' creative thinking. Few studies focus on STEM education models that can enhance students' creative thinking abilities.
3. Future research should use larger sample sizes and mixed methods to obtain in-depth results that can be generalized to the entire population and maximize the benefits of implementing STEM education at higher educational levels.

**Author Contributions:** All authors contributed equally to the conceptualization, data collection, analysis, writing up, and revision of the final version of this manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** This study did not require ethical approval, however the study was conducted in accordance with the United Arab Emirates University's research regulations.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data are available from the corresponding author upon reasonable request.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A. Sample of Stem-based Lesson Plan and Worksheets (Smart Car Design Lesson Plan)

- Target Grade:10th
- Time Required: 3 days, 50-min lessons

### Standards

*Next Generation Science Standards (NGSS):*

- HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.
- HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).
- HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in designing materials.

### Lesson Objectives

Students will be able to:

- Identify how friction generates heat.
- Quantify the energy released to the environment as heat to mathematically prove that the energy put into a system equals the energy that comes out of the system.

### Central Focus

In this lesson, Students will create a Project -based on inquiry involving force, friction, and energy. They will begin the lesson by traveling to different stations to get hands-on experience with each topic. They will then develop their own experiments to support their claim of their given topic. To end the lesson, students will present their question, investigation, and evidence and technology used in a project that will be presented to the class to finalize a conclusion on a given physics topic.

In this Task, you will use your designing Skills and your physics knowledge about momentum collision, Friction, speed, and velocity to design your New Model of the TESLA CAR to solve the issues related to speed Versus friction in order to enhance the level of safety and health measurement.

**Key terms:** Newton's Laws, motion, energy, motion, collaboration

### Background Information

Students will need to have some prior knowledge of atomic structure and energy and to connect that information to Newton's Laws, friction, the Law of Conservation of Energy, and rotational motion. The lesson also delves into advanced chemistry and physics with discussions of entropic forces, thermodynamics, resistive heating, friction welding, and aerodynamic friction. These are not typically included in regular-level high school physics.

### Materials:

- Computers/tablets
- Simulation software (e.g., MATLAB, Simulink)
- Computer with modeling tools
- Data collection tools for real-world comparison
- Small solar panel
- Power management circuit
- Battery storage
- Wiring and connectors
- Various materials for wheels (rubber, plastic, metal)
- Prototyping materials (3D printing materials, modeling clay)
- Testing surfaces with different friction characteristics
- Computer with data analysis software (e.g., Excel, Python)
- Sensors for data collection
- Graphing tools
- Emergency braking system components (sensors, actuators)
- Microcontroller for control logic

- Wiring and connectors
- Obstacle objects
- Simulated urban environment materials (miniature road markings, obstacles)
- Smart car prototype
- Power source (battery)
- Testing area setup with various road conditions
- Microcontroller (e.g., Arduino)
- Wiring and connectors
- Power source (battery)
- Testing apparatus with adjustable surfaces
- Force sensor
- Smart car prototype with adjustable wheels
- Inclined surfaces.
- Computer Model for Friction and Motion
- Simulator for Frictional forces
- *Friction & Work Activities* worksheet

### Instruction

*Day 1: Define the problem.*

The Insurance Institute for Highway Safety has rated the Tesla Model 3 car with 5 stars during the recent crash test, The New Design needs to Solve all Tesla's weakness as **body construction**, Munro" said. Some areas of the Model 3 consist of too many parts, like its wheel wells, and the vehicle features multiple kinds of welding techniques, **Car Crash and Speed versus friction.**

- Before class, the teacher will need to set up five stations around the room.
- The five stations are the following:
  - PhET Simulation: The teacher will need to put one or two laptops/tablets at a table.
  - Simulate Your Ideas—Use the Simulator of Collision Lab model your physics knowledge
  - Sand Jar: Set up a jar with either sand or gravel inside. The students will need a thermometer to record temperature and a jar lid.
  - Rubber Band: Place a bag of rubber bands and a trashcan on the table.
  - Hot Wheels: Students will need some type of recording device (can be cell-phone, ipad, etc.), a ruler, track, and a hot wheel's car.
  - Bow Drill: Students will need some type of device to watch the given YouTube video.

*Introduction:*

- When the students arrive in the class, the teacher should split them into five groups.
  - Each student will need a copy of the Friction & Work Activities worksheet.

*Exploration:*

- On the student's worksheet, they will conduct an inquiry-based task to create their project of smart cars. The students will gather photos, video, and/or numeric evidence from the following activities to support their claim conclusions.
- The possible questions the students can investigate about:

*Design Challenges:*

- How can you design a smart car that maximizes energy efficiency and minimizes friction for optimal motion?
- What are the key components and materials that can be used to reduce friction in the car's movement?

*Friction Analysis:*

- How does friction impact the motion of a vehicle, and how can it be both advantageous and disadvantageous in a smart car design?
- Can you identify specific areas in a smart car where friction is most critical, and propose innovative solutions to minimize it?

*Energy Efficiency:*

- What role does friction play in energy consumption within a smart car, and how can students optimize the car's design for energy efficiency?
- Can you explore renewable energy sources or regenerative braking systems to enhance the smart car's sustainability?

*Sensor Integration:*

- How can sensors be integrated into a smart car to detect and respond to changes in friction and motion?
- What types of sensors would be most effective, and how would they contribute to the overall performance of the smart car?

*Smart Car Control Systems:*

- What control systems can be implemented to adjust the smart car's motion based on real-time friction data?
- How can machine learning algorithms be utilized to enhance the smart car's ability to adapt to varying friction conditions?

*Real-world Applications:*

- How can the principles of motion and friction be applied to real-world scenarios, such as urban traffic, to improve the efficiency and safety of smart cars?
- Can you design a smart car that addresses specific challenges in transportation, such as reducing traffic congestion or minimizing environmental impact?

*Safety Considerations:*

- How do motion and friction affect the safety of a smart car, and what safety features can be incorporated into the design to mitigate risks?
- Can you explore the balance between speed and safety in a smart car, taking into account factors like braking distance and reaction time?

*Materials Engineering:*

- How can different materials be used in the construction of a smart car to optimize friction and motion characteristics?
- What are the trade-offs between using traditional materials and newer, advanced materials in the context of motion and friction?

*Data Analysis:*

- How can data collected from the smart car's sensors be analyzed to make informed decisions about optimizing its motion and friction?
- What insights can be gained from the data to continually improve the smart car's performance?

*Environmental Impact:*

- How can the design of a smart car contribute to reducing its environmental impact in terms of energy consumption and friction-related wear and tear?
- Can you propose sustainable practices in the manufacturing and use of smart cars to minimize their ecological footprint? The station descriptions are the following:
  - **PhET Simulation: Students will open a simulation that explores friction by Forces and Motion** or "The Moving Man" simulations can be adapted to understand acceleration, velocity, and the forces acting on an object.
  - Groups will travel to the Computer Model station to study all the factors -Variables related to their Design **Raspberry Pi**. The Raspberry Pi is a versatile, low-cost, credit-card-sized computer that is widely used for educational

purposes, including STEM education. It can serve as the brain of a smart car prototype, allowing students to program and control the car's behavior.

- Groups will conduct a deep investigation to answer the previous questions and record them in their Journals.
- After the students have completed the stations, their group will devise their own experiment to collect at least three pieces of photo/video evidence to support their conclusion to their Science Project.
- Students will brainstorm what materials their group will need to collect their data.
- They will end the lesson by reflecting on what they learned that day and ideas for their Science-Project.

## Appendix B. Torrance Tests of Creative Thinking

**Name: Gender: Age: Grade:**

### Ideational Fluency Metric Test

#### Part 1:

##### Exam Instructions:

In this examination, your task is to identify and enumerate items associated with a specific category. For instance:

Example:

Category: Flammable Liquids

Items: Usable liquids, gasoline, kerosene, alcohol

During the test, you will be presented with the name of a particular group, and your objective is to provide a comprehensive list of various objects and materials that fall within that category. Promptly record all relevant items that come to mind associated with the given group.

Each segment of the examination consists of four parts, and you are allocated two minutes for each part. Ensure efficient use of your time to provide thoughtful and accurate responses.

Q1. List solid things that sink in water.

Q2. List recyclable materials.

Q3. List measuring tools.

Q4. List things attracted by magnets.

### Verbal Fluency Metric Test

#### Part1:

##### Exam Instructions:

In this examination, your task is to generate as many words as possible that commence with the designated letter. The assigned letter will be provided on the first page of each question. Refer to the following pages for additional guidance:

Example: Write as many words as possible starting with the letter (B). For instance, you can list words like bag, body, book, etc. It is crucial to observe that all words must start with the specified letter. Furthermore, please note that names of individuals and places are not permissible and emphasize the significance of the speed factor.

Q1. Write as many scientific words starting with the letter K as possible.

Q2. Write as many scientific words starting with the letter C as possible.

Q3. Write as many scientific words starting with the letter A as possible.

##### Exam Instructions:

In this examination, your task is to generate as many words as possible within the specified parameters. Consult the instructions provided on the first page of each question for guidance.

Example: Write as many words as possible ending with the letter (R). For instance, you can list words like actor, bigger, etc. Please note that all words should end with the specified letter, and names of individuals and places are not permissible. Emphasize the importance of speed while responding.

The examination comprises three distinct parts, and you are allotted a two-minute timeframe for each section. Ensure efficient utilization of your time to complete each part.

- Q1. Write as many scientific words ending with the letter N as possible.
- Q2. Write as many scientific words ending with the letter D as possible.
- Q3. Write as many scientific words ending with the letter K as possible.

### Unusual Uses Test—Cognitive Flexibility Metric

#### Exam Instructions:

This assessment is designed to evaluate your capacity to generate innovative applications for familiar objects, showcasing your ability to think creatively. Consider the following:

Example:

Familiar object: Paper clip

Normal use: To hold papers.

Unusual uses: Utilizing it as a fishing rod.

Carving wood for writing or drawing.

Employing it to clean nails.

It is imperative to recognize that the validity of your response is contingent upon meeting two conditions: deviation from the object's original purpose and distinction from other listed uses.

The examination comprises two parts, and you are granted a four-minute duration for each segment. The emphasis is on swift and inventive thinking to optimize your performance.

- Q1. Write as much as you can about unusual uses for the skateboard (standing or crouching position, propelling)



- Q2. Write as much as you can about unusual uses for a big cardboard box (packaging)



- Q3. Write as much as you can about unusual uses for a car (transportation) or parts of it.



- Q4. Write as much as you can about unusual uses for a metallic spring (connect two pieces). Use your prior physics knowledge.



Q5. Write as much as you can about unusual uses for a tennis racket (playing tennis, hitting the ball). Use your prior physics knowledge.



Q6. Write as much as you can about unusual uses for a light bulb (produces light from electricity). Use your prior physics knowledge.



### Consequences Test—Elaboration Metric

#### Exam Instructions:

This examination assesses your capacity to generate a multitude of outcomes in response to unique or unfamiliar situations. Consider the following:

Example: What would happen if people stopped needing to sleep?

Consequences/Results:

Increased production.

Elimination of the need for alarm clocks.

Reduced dependence on sleeping pills.

Numerous other consequences may arise if people cease to require sleep.

Throughout the exam, you will encounter five scientific scenarios like the example provided. Each scenario will be accompanied by a two-minute timeframe for your response. Your task is to articulate as many outcomes as possible stemming from the given situation. Responses need not be in the form of complete sentences. Swift and comprehensive thinking is encouraged.

Q1. What would happen if a person lost the ability to balance and became unable to stand upright for more than a minute?

Q2. What would happen if the Earth's gravitational force was halved?

Q3. Suppose you could walk on air or fly without being in an airplane or similar vehicle.

What problems might this create? List as many as you can.

Q4. Suppose you could be invisible for a day.



What results might this create?

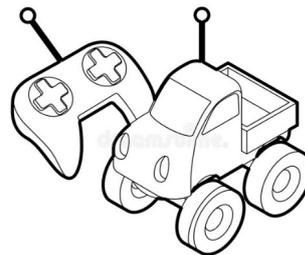
What would the benefits of being invisible be?

Q5. What would happen if we suddenly lost the ability to move our hands?

Creative Thinking Test Using Words—Originality Metric

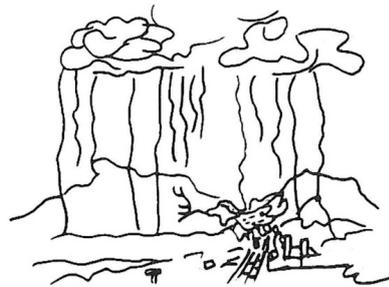
### Production Improvement

Q1. This question presents a visual depiction of a children’s toy—a 16 cm long electronic car with a controller, weighing 500 g. Your task is to contemplate strategies that can enhance the toy’s resistance to friction as its speed increases. The objective is to transform the modified toy into a source of enjoyment and delight for children. Discuss the most innovative, unconventional, and captivating modifications for this game.



Disregard cost considerations in your responses and focus solely on elements that can amplify the joy and pleasure derived from playing with this toy. You are allotted ten minutes to address this question. Demonstrate creativity and respond promptly.

Consider the following hypothetical scenario, engaging your imagination and speculating on the potential outcomes resulting from a situation that may never transpire. Assume, for this exercise, that the described situation has indeed occurred. Subsequently, reflect on the manifold consequences or developments that might ensue because of this imaginary scenario.



The unlikely situation: Envision a circumstance where threads hang from clouds, connecting them to the Earth. Contemplate and document all conceivable thoughts and conjectures about the possible consequences of this fantastical situation.

You are granted ten minutes to address this question, encouraging thoughtful exploration of imaginative possibilities.

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