

STEM Education Between Tradition and Innovation: A Comparison of Teaching Methods in Traditional and Waldorf Education

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Abstract

Keywords:

STEM, Waldorff, development of creativity, theory with practice

In a rapidly changing global context, education must evolve to meet the needs of modern society. Traditional and alternative education systems, such as the Waldorf approach, adopt different methods to shape students' learning experiences. While traditional education focuses on knowledge acquisition through memorization and standardized assessments, the Waldorf system promotes a holistic approach, emphasizing experiential learning, the development of creativity, and the integration of theory with practice. This comparative study analyzes the impact of both systems on the teaching of chemistry and physics, highlighting the differences between theoretical and experiential learning. The research was conducted on a sample of 100 students and evaluated each model's effectiveness in developing critical thinking, scientific problem-solving, and creativity. Students in the traditional system followed a lecture-based approach with tests, while those in the Waldorf system actively participated in experiments, interdisciplinary projects, and hands-on activities. The results reveal significant differences between the two methods. Traditional education provides a structured and clear framework but may limit students' autonomy. On the other hand, the Waldorf method fosters innovation and the flexible application of knowledge, facilitating deeper and more adaptable learning. This study provides valuable insights into how educational strategies influence the development of essential competencies for the future.

1. Introduction

In the context of the knowledge society and the transition toward a competence-based educational model, education systems worldwide are facing the need to reconfigure their pedagogical paradigms. Technological transformations, globalization, and the new demands of the labor market require a rethinking of how education prepares new generations for the challenges of the future (Bybee, 2010; National Research Council, 2011). Within this framework, STEM education (science, technology, engineering, and mathematics) gains strategic importance, being perceived as a key driver of sustainable development and innovation (Kerekes, 2022).

In his foundational works on educational theory and general pedagogy, Albulescu (2002) emphasizes that education cannot be conceived outside its socio-cultural context and humanistic purposes. He underlines that the goal of education is not merely the transmission of knowledge, but also the formation of a balanced personality capable of adaptation, critical thinking, and creativity.

This perspective challenges the effectiveness of an educational system that privileges only the cognitive

dimension while ignoring the emotional, motivational, and social components of the learning process.

Traditional education, characterized by the teacher's authoritative role, frontal transmission of knowledge, and standardized assessment, remains dominant in Romanian schools and in many other educational systems. This pedagogical model promotes reproductive learning and cognitive conformity, which, according to Albulescu (2014), can lead to the formation of well-instructed students, yet with a deficient education—lacking initiative and creativity.

In contrast, the Waldorf alternative education model proposes a holistic approach to student development, integrating intellectual, artistic, and practical dimensions. Rooted in Rudolf Steiner's anthroposophy, this pedagogy values the natural development of the child, encouraging learning through experience, creative activities, and authentic social interactions (Jelinek & Sun, 2003; Ogletree, 1996). In the Waldorf vision, science is not taught as an isolated discipline, but as part of an integrated learning experience that stimulates curiosity,



observation, and direct experimentation with phenomena.

This research aligns with contemporary efforts to evaluate educational methods through comparative analysis, offering an investigation of how STEM is taught within two different paradigms: the traditional system and the Waldorf model. The focus is on the teaching of chemistry and physics—disciplines essential for the development of scientific thinking, yet often perceived as abstract and inaccessible in conventional education. The study explores the differences between theoretical and experiential learning, between standardized assessment and reflective self-evaluation, between rigid structure and creative flexibility.

By incorporating the principles outlined by Albulescu and drawing on international literature on STEM education, this research aims to provide a balanced perspective on the strengths and limitations of each model. At the same time, the study raises the need for a balance between scientific rigor and the stimulation of creativity, between tradition and innovation—essential conditions for relevant and sustainable education.

2. Theoretical foundation

In an educational landscape increasingly shaped by rapid transformations and the imperative to align with the demands of a knowledge-driven and innovation-oriented society, educational systems are compelled to rethink their strategies for student development. STEM education (Science, Technology, Engineering, and Mathematics) has emerged as a global priority, viewed as a cornerstone for long-term economic resilience and technological progress (Honey et al., 2014; Marginson et al., 2013). However, the ways in which STEM subjects are taught differ substantially across educational paradigms, raising important questions regarding the comparative effectiveness of traditional versus alternative teaching models.

The traditional education system, dominant in public schooling across many countries, remains rooted in teacher-centered instruction, a focus on theoretical knowledge transmission, and standardized evaluation methods. While this model can be effective in organizing information and providing a structured learning environment, it has been widely criticized for constraining creativity, limiting learner autonomy, and hindering the real-world application of knowledge (Sawyer, 2014; Zhao, 2012). In contrast, the Waldorf alternative education model promotes a holistic and

experiential approach, aiming to integrate cognitive, emotional, and practical dimensions of learning (Edwards, 2002; Nicol & Taplin, 2009).

This dichotomy between traditional and alternative education brings forth essential considerations regarding the capacity of each model to foster key 21st-century competencies: critical thinking, creativity, problem-solving, and the ability to transfer knowledge into authentic contexts. This is particularly relevant in the teaching of subjects like physics and chemistry, where deep conceptual understanding requires both theoretical insight and hands-on application. A comparative analysis of student outcomes in these two educational systems is therefore necessary.

The present study addresses this need by investigating and comparing the effectiveness of STEM teaching approaches within traditional and Waldorf frameworks, focusing on their impact on scientific reasoning, creativity, and practical application skills. At the core of this research lies the central question: to what extent do the instructional methods characteristic of each system contribute to the development of competencies relevant to contemporary society?

3. Research methodology

The general aim of this research is to conduct a comparative analysis of the impact of STEM teaching methods within two distinct educational paradigms – the traditional system and the alternative Waldorf system – on the development of specific competencies in the fields of chemistry and physics.

3.1. Specific objectives:

1. To identify the defining characteristics of STEM instruction in traditional education and in the Waldorf system.
2. To evaluate the effectiveness of teaching methods in relation to the development of critical thinking, creativity, and problem-solving skills.
3. To conduct a comparative analysis of student performance based on the type of instruction (theoretical vs. experiential).

3.2. Research Hypotheses

H1: Students educated in the Waldorf system demonstrate higher levels of creativity and autonomy in solving scientific problems compared to students in the traditional system.

H2: Teaching STEM subjects through experiential methods, as practiced in the Waldorf system, leads to deeper and more enduring learning than the predominantly theoretical instruction in the traditional system.

H3: There are significant differences in student performance on applied tasks (experiments, interdisciplinary projects) depending on the type of education received.

3.3. Research Design

This study follows a quantitative and comparative research design, aiming to identify differences between two groups of students from traditional and Waldorf educational systems regarding their outcomes in learning STEM subjects.

3.4. Research Sample

The study was conducted on a sample of 100 lower secondary students (grades 7–8), equally divided into two groups:

- 50 students from schools following a traditional teaching model.
- 50 students from accredited Waldorf institutions.

The sample was selected using stratified sampling, ensuring balance across age, gender, and academic level.

3.5. Research Instruments

- STEM competency assessment tests, designed based on the national curriculum and aligned with PISA evaluation frameworks.
- Observation sheets tracking student behavior and participation during practical activities.
- Questionnaires and self-assessment forms exploring students' perceptions of their learning experiences.
- Project portfolios and experimental activity logs, documenting applied work.

Students participated in activity sets specific to each system (theoretical lessons vs. practical experiments and interdisciplinary projects). Data collection was carried out throughout the 2024–2025 school year. Student performance was analyzed using statistical methods (mean, standard deviation, and t-tests) to determine significant differences between the two groups.

Student participation was granted with the informed consent of parents or legal guardians, and

data collection and analysis were conducted in compliance with confidentiality and anonymity principles.

4. Results

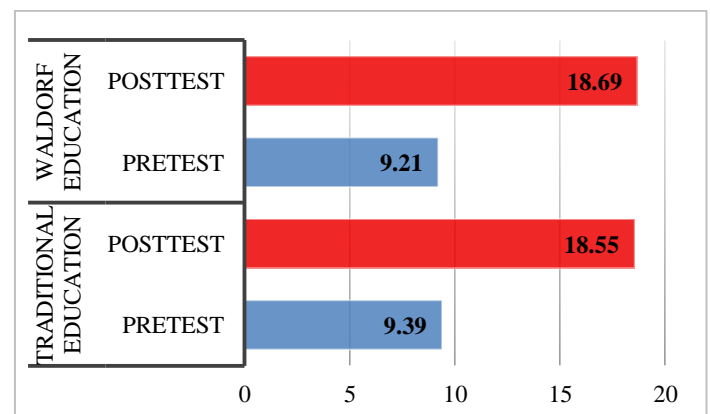
The analysis of the collected data was conducted using both descriptive and inferential statistical methods, with the goal of identifying significant differences between students in the traditional and Waldorf systems regarding their STEM-related competencies.

The research, which included the administration of both a pre-test and post-test across several schools, aimed to assess the development of competencies within traditional and Waldorf educational models. The results did not reveal significant differences between the two methods, suggesting that both approaches can contribute similarly to the development of students' competencies.

The questionnaires administered were designed to measure progress in specific skills and competencies, confirming the importance of diverse educational strategies in the learning process.

Figure 1

Comparison of results between the traditional education group and the Waldorf group



5. Data Interpretation and Analysis

According to the data presented in Figure 1, both the traditional education group and the Waldorf group started from comparable levels of development in the measured competency (denoted as V.D), with initial values of 9.39 and 9.21, respectively. After one academic year and the implementation of instructional activities in both systems, a slight difference of 0.32 was recorded between the two groups. This variation was statistically insignificant, allowing the conclusion that the differences in overall outcomes were not meaningful from a statistical standpoint.

To assess creativity, autonomy, and scientific problem-solving skills, multiple tools and diverse activities were used. Students created thematic posters that reflected their personal understanding and interpretation of the studied concepts. In addition, practical experiments—some conducted at home—allowed observation of students' autonomy and responsibility in carrying out scientific tasks. Individual portfolios included complex projects, reports, and video materials documenting the investigative process, creative thinking, and original approaches to solving problems.

These components were integrated into a dependent variable (referred to as V.D.CASP – Dependent Variable of Creativity, Autonomy, and Scientific Problem-solving), which reflected students' overall performance in the targeted areas. Results obtained through the t-test indicated that students in the Waldorf system demonstrated higher levels of creativity, autonomy, and scientific problem-solving skills compared to those in traditional education. These findings underscore the effectiveness of the Waldorf approach in fostering such competencies.

H1. Students studying within the Waldorf educational system demonstrate a higher level of creativity and autonomy in solving scientific problems compared to students from the traditional education system.

According to the data analysis presented in Table 1, a significant increase in the mean score for the dependent variable V.D.CASP was recorded among students in the Waldorf group, reaching a value of

5.6512, compared to 4.2357 in the traditional group, as indicated by the t-test. This difference reflects a higher level of creativity and autonomy in scientific problem-solving among Waldorf-educated students.

The results support the existing literature, which emphasizes the benefits of Waldorf pedagogy in fostering creativity and autonomy through a holistic approach that integrates the arts, hands-on activities, and experiential learning (Edwards, 2017). Moreover, recent longitudinal studies confirm a significant increase in creative competencies and autonomy among Waldorf students compared to those in traditional systems (Kunzmann & Schecker, 2020).

Table 1

Data and mean results collected following the application of the t-test for the comparison of the dependent variable V.D.CISP between the traditional education group and the Waldorf group

	Group	N	Media	Mean difference	Standard error difference
VDCISP	Traditional education	50	6,129	4,6281	,56112
	Waldorf education	50	8,166	5,8324	,60954
VDCISP	Traditional education	50	14,321	4,2357	,52135
	Waldorf education	50	18,333	5,6512	,63328

This method also promotes critical thinking and the ability to independently solve scientific problems by incorporating art and experimental methods into the curriculum (Miller, 2019), thus highlighting the advantages of Waldorf education in developing essential competencies for both academic and personal success.

Table 2

Data collected from the application of Levene's test for the comparison of the dependent variable V.D. between the traditional education group and the Waldorf group

VD	Levene's test for equality of variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Standard error difference	95% Confidence Interval for the Differences	
								High	Low
Equal variances assumed	,150	,700	,100	127	,920	,02000	,02000	-0,370	0,410
Equal variances not assumed			,120	126,99	,905	,0030	,250	-0,460	0,520
Equal variances assumed	,638	,426	0,612	127	,541	0,482	0,788	-1,077	2,041
Equal variances not assumed			0,612	126,375	,539	0,473	,782	-1,055	2,001

6. Discussions

6.1. Testing Hypothesis H₃

To test hypothesis H₃, which states that "There are significant differences in students' performance on

applied tasks depending on the type of education received (traditional or Waldorf)," the results of various applied activities conducted over the course of an academic year were analyzed. These activities included individually and collaboratively conducted

scientific experiments, integrated projects combining disciplines such as science, art, and technology, explanatory thematic posters, simple functional prototypes, a final assessment, as well as documented portfolios reflecting both the process and the final outcome of the students' work.

Student performance was evaluated using a standardized rubric based on the following criteria: originality, autonomy in problem-solving, scientific applicability, logical coherence, and quality of presentation. The results were coded into a dependent variable named V.D._{AP} (Applied Performance).

To determine whether the differences between the Waldorf and traditional groups (as shown in Table 3) were statistically significant, Levene's test for equality of variances was first applied. The result was $F = 0.638$, with a significance level of $p = 0.426$, indicating that the variances are homogeneous ($p > 0.05$) and that the analysis could proceed under the assumption of equal variances.

Subsequently, an independent samples t-test was conducted, producing the following values: $t = 0.612$, degrees of freedom = 126.375, and $p = 0.541$ ($p > 0.05$). The mean difference between the two groups was 0.482, with a standard error of 0.788, and the 95% confidence interval for this difference ranged from -1.077 to 2.041.

Based on these results, it is concluded that there is no statistically significant difference between the applied performance of students educated in the Waldorf system and those in the traditional system. Therefore, hypothesis H_3 is not supported by the data.

6.2. Testing Hypothesis H_2

To test hypothesis H_2 , which posits that "Experiential STEM instruction in the Waldorf system leads to deeper and more durable learning compared to theoretical instruction in the traditional system," the study compared learning effectiveness across the two systems in terms of depth and retention of knowledge in STEM subjects (science, technology, engineering, and mathematics).

Durable learning was assessed through a longitudinal design, using a pre-test at the beginning of the observation period and a post-test at the end of the academic year. The same measurement tools were applied in both instances.

The assessments measured conceptual understanding, knowledge transfer to new contexts, practical application ability, and clarity in scientific

expression. The scores were recorded as a dependent variable named V.D._{DL} (Durable Learning).

Statistical analysis included Levene's test for equality of variances, which indicated homogeneity ($F = 0.638$, $p = 0.426$), allowing for the use of an independent samples t-test under the assumption of equal variances.

The t-test results were as follows: $t = 0.612$, $df = 126.375$, $p = 0.541$. The mean difference between the Waldorf and traditional groups was 0.482, with a standard error of 0.788, and a 95% confidence interval ranging from -1.077 to 2.041.

These results indicate that there are no statistically significant differences between the two groups in terms of durable learning of STEM content. Although the experiential methods promoted by the Waldorf system are known for their integrative and applied nature, the data do not support the hypothesis that they lead to significantly deeper and more lasting learning compared to the theoretical methods characteristic of the traditional system.

In conclusion, hypothesis H_2 is not confirmed, as the observed differences between the groups do not reach statistical significance.

7. Discussions

The results of the study indicate that although the educational approaches used in the Waldorf and traditional systems differ significantly in their pedagogical design, no statistically significant differences were identified in the measurable applied performance between the two groups of students. The statistical analyses conducted (Levene's test: $F = 0.638$, $p = 0.426$; $t = 0.612$, $p = 0.541$) show that the mean differences in the dependent variable V.D._{AP} (Applied Performance) are not statistically relevant, leading to the rejection of hypothesis H_3 regarding the superiority of one educational model over the other in this regard.

However, based on qualitative data and documented observations during the applied activities, students from the Waldorf system demonstrated higher levels of creativity, personal initiative, and autonomy in addressing applied tasks—particularly in the execution of scientific experiments, interdisciplinary projects, and thematic portfolios. These students proposed more original solutions, showed greater openness to exploration, and integrated interdisciplinary knowledge in a more natural and authentic manner.

Therefore, although quantitatively measurable performance does not differ significantly, it can be argued that the Waldorf methodology fosters essential dimensions of personal development—such as decision-making autonomy, creative problem-solving, and critical thinking—which are not always captured by standardized assessments but are crucial for the long-term development of STEM competencies.

These findings support the notion that an exclusively quantitative evaluation of performance may overlook valuable aspects of the educational process, particularly those related to transversal competencies, intrinsic motivation, and active student engagement. In this context, a mixed-method approach, combining quantitative and qualitative tools, is recommended to more accurately reflect the true impact of different educational models.

In conclusion, both the Waldorf and traditional educational systems offer distinct advantages. Integrating the strengths of both models into a flexible, student-centered educational framework may represent a productive direction for future development. The observed differences in learning styles, engagement, and student autonomy highlight the potential of the Waldorf method to foster a more personal and meaningful relationship with science, even if this is not immediately reflected in statistically significant differences in standardized evaluations.

Authors note:

Kerekes Jenő is a chemistry and physics teacher at "Váradi József" Secondary School and "Nicolae Colan" Secondary School in Sfântu Gheorghe—two institutions that place strong emphasis on educational quality and student well-being. In parallel, he has carried out applied electronics and experimental chemistry activities at the Children's Palace in Sfântu Gheorghe, where I currently serve as director. This research is a continuation of the study conducted during my PhD in the curricular field of Mathematics and Natural Sciences. It focuses on a comparative analysis between traditional education and the Waldorf approach, while also integrating elements inspired by the non-formal activities developed at the Children's Palace. The aim is to highlight the complementary potential of creative, technical, and scientific methods in enhancing and diversifying the educational process within both paradigms. The doctoral research was conducted under the supervision of Professor Dr. Habil. Ion Albulescu.

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