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The Secret of Women in Physics: Finding Motivations

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ABSTRACT

Why is there an under-representation of women in physics? What can teachers encourage women to learn about physics? We want to analyze the motivations behind studying physics at pre-university educational levels. 69 high school students who learned with a Brain-Based Teaching Approach (BBTA) methodology (Socratic-Maieutic style) were compared to a sample of the same N who had learned in a masterclass style. The BBTA group learned through four main steps: establishment of affective bonds between the student and the subject, argumentative class as a tool to judge (maieutic style), contextualization, and experimentation. Both groups were analyzed using the Academic Motivation Scale (AMS). The t-test and U Mann-Whitney analysis suggest that amotivation (lack of motivation) is the same in both groups, but extrinsic motivations (related to external rewards) are higher in the classic style group, while intrinsic motivations (related to internal rewards) are higher in the Socratic style, especially for women ($p < 0.032$). Learning physics reinforces intrinsic motivation if we consider the way the brain works.

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Introduction

Although women mature brains earlier than men in adolescence, this advantage does not make any difference in the decreasing number of women studying physics. How can we motivate women to study physics? First, we need to examine the topic to find answers and possible solutions.

Preconceptions and misconceptions are well known in learning physics processes in every area of this subject, such as kinetics, energy and momentum, vectors, and dynamics [1-4]. It is a never-ending list. Although these preconceptions and misconceptions have been shown and identified in an extensive bibliography, there is no clear way to avoid them.

These difficulties are not a consequence of a singular way of teaching or learning the subject, but are intrinsic in learning physics [5, 6]. This global difficulty is related to the way the brain learns formal content, which is linked to the frontal lobe and its executive functions. However, the characteristics of the scientific methods of physics are far from intuitive.

Myelination of the frontal lobe occurs during adolescence. Decision-making mechanisms are being developed for executive functions [7].

The prefrontal cortex plays an inhibitory role in learning physics. The brain has not yet achieved reorganization of neural networks [8]. We understand natural phenomena through our intuitions before we obtain a formal explanation. This leads to the appearance of prejudice.

The mental patterns created require time and effort to change to the proper ones. This is a strong reason why paradigms in science have been modified so slowly throughout history. As a first step in changing this pattern, we need explicit attention.

The brain has evolved to make rapid decisions. This represents difference between life and death. Formal explanations require formal education [9].

To overcome this prejudice, more laboratory sessions and physics should be taught as soon as possible in primary schools, at a comprehensive level for the students [10]. It is also important to know the interests of students to create affective bonds with the subject.

It would also help if we could link physics with different subjects, such as Biology, Mathematics, Philosophy, History, Music or Geography. We learn transversally, linking everything that we already know [11]. The implication of the students in their own learning process is what we obtain through this methodology.

Prior brain-based learning procedures have yielded better results for students and higher intrinsic motivations. We find a theoretical framework linking the brain and learning physics in Redish´s research in physics education (2003) or the Brain-Based Teaching Approach (BBTA) proposed by Caine and Caine (2003) [12, 13].

Freeman and Wash (2013) showed that learning physics, taking into account the way the brain works, creates a win-win situation, increases the academic performance, and improves college students´ attitudes toward the subject. Saleh (2011) indicated that students are more motivated [14, 15].

The BBTA procedure has provided a better understanding of Newtonian laws [16].
Different authors, such as Tüfekçi (2009) and Worden, Hinton, and Fischer (2011), have proven that a brain-based learning environment has a positive effect on the quality of the learning process, retention, and attitude [17, 18]. At this point, it is important to discover that educators and neuroscientists should work together to improve teaching strategies.

The applied methodology is related to this theoretical framework and has been developed for Spanish students, even though it could be applied in different countries [19]. This is mainly based on the engagement of students using selected movie clips and maieutic discussions. The teacher guides students through observation and intuition to reach formal concepts.

It is important to highlight that all of these references in the introduction allow the establishment of an adequate, coherent, and properly based teaching method. The method was developed and implemented by a neuroscientist and physicist, and there are more details in a complete and fully developed example for Newtonian laws [19].

Are those educational principles enough to engage women in physics?
Women in science are not as integrated as men are. This is also a global phenomenon. There was no difference in aptitudes, intelligence, or experimental skills between men and women. This has already been shown in neuroscience [20]. This is probably due to social prejudice or even a lack of confidence in dealing with science [21]. The situation is not different in Spain, as shown by the Spanish Royal Physics Society at high school (2015) and university levels (2021) [22, 23].

Gender stereotypes and a social activist orientation are frequent reasons for the underrepresentation of women in physics [24].

The most precipitous drop in women's representation occurs between high school and university, as Skibba (2019) shows [25].

Females perceive that they are less numerically, compared to males in a science class, and this is a possible explanation for the difference in gender performance [26]. This implies that parity is necessary to overcome the possible inferiority complexes in science or prejudice that females may have concerned themselves, predisposing them to underrate their own capabilities. There was no difference in male and female performance when parity occurred [27].

The current physics-learning environment is definitely one of the powerful reasons that explains the underrepresentation of women in physics [28]. We want to determine if the BBTA methodology applied is useful for motivating women to learn physics.

Methods
The Spanish Academic Motivation Scale (AMS) test was used in this study. The validity of the test has already been proven for 12-16 years old students and 16-18 years old students [29, 30]. Vallerand et al. (1992) suggested three factors for intrinsic motivation: the intrinsic motivation to know (IMTK), which means that the student performs the activity for the pleasure that they feel when they get a new learning; the intrinsic motivation to accomplish (IMTA), which means that the student interacts with the environment to feel competent; and Intrinsic Motivation to Experience Stimulation (IMES), which means the student engages in the assignment to experience stimulation [31]. The three factors of intrinsic motivation exist on the continuum of self-determination, but they are factors of intrinsic motivation with a correlation between each other. Three factors for extrinsic motivation are extrinsic motivation for external regulation (EMER), which means that the student performs the activity in order to obtain external reinforcement; extrinsic motivation for introjected regulation (EMIN), which means that the student begins to personalize his actions reasons; extrinsic motivation for identified regulation (EMID), which makes the behavior valuable and important for the student; and one factor for Amotivation (AMOT), which means that the student does not have intrinsic or extrinsic motivation.

Participants
As in previous studies, the sample fulfills the following parameters. Middle class students from high school attending physics classes at pre-university levels (age range: 15 – 18 years) from Madrid, Spain [19].

36 male (52,2%) and 33 female students (47,8%) students were chosen for this study. Even though the original sample comprised 112 students, only N = 69 fulfilled all the criteria requirements.

Two groups were compared; control and intervention groups. In the intervention group, the methodology described above was applied. In the control group, students from different high schools were learning in a classic master class style.

Various criteria have been used to choose a statistical population, always seeking the sample to be as homogeneous as possible. Exhaustive criteria were used to avoid masking variables.

Inclusion criteria are:
1. Students must take the corresponding course, according to age.
2. We wanted to study the effects of this specific teaching method. This implies that the position of the method must be as high as possible. Therefore, students from the intervention group must have completed the previous courses with this methodology from the age of 15 onwards.

As previously mentioned, the samples must be as homogeneous as possible to avoid unintended effects. For this reason, the exclusion criteria were as follows:
1. Students must not be foreigners, must not have spent two or more years living abroad, or have established social routines belonging to other cultures (to avoid language difficulties or cultural gaps in the maieutic discussions).
2. Students must not suffer from any neurological pathologies (such as AD/ADHD, dyslexia, aphasia, tumors, etc.) Regular and normally developing brains are needed. This is the first step in implementing this methodology for inclusive schools in future research studies.

Control group is chosen from two different high schools. Students fulfilled common criteria.

Written informed consent was obtained from all participants and parents prior to testing.
All p-values were 2-sided, and p-values below 0.05 were considered significant. All analyses were performed using IBM SPSS (version 25.0; SPSS Inc., Chicago, IL, USA) and Stata 16.

Data Availability
The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Results
The characteristics of the samples are shown in Table 1.

Table 1: Characteristics of the sample groups by sex and age. We can see the number of participants in each course with two different methodologies: A Brain-Based Teaching Approach (BBTA method) and master class (classic method).

		BBTA method			Classic method		
	Age	Male	Female	Total	Male	Female	Total
Course 1	15-16	19	12	31	19	12	31
		(61%)	(39%)	(100%)	(61%)	(39%)	(100%)
Course 2	16-17	9	12	21	17	21	38
		(43%)	(57%)	(100%)	(45%)	(55%)	(100%)
Course 3	17-18	8	9	17			
		(47%)	(53%)	(100%)			
Total		36	33	69	36	33	69
		(52%)	(48%)	(100%)	(52%)	(48%)	(100%)

Both samples had approximately the same distribution according to sex (52% of men and 48% female).

The direct scores for both samples are shown in Table 2. The groups were analyzed without considering sex-related difference.

Table 2: Direct scores of BBTA and classic samples

	BBTA method		CLASSIC method	
IMTK	5.5109	1.00315	5.1558	1.19980
IMES	4.4348	1.20022	4.2065	1.21037
IMTA	5.0217	1.14383	5.0507	1.23266
AMOT	1.6123	.89065	1.7101	.88764
EMER	4.9130	1.42317	5.6630	1.22236
EMID	5.7500	.91956	6.0290	.87083
EMIN	4.1703	1.38698	4.7609	1.25545

The amotivation and extrinsic motivation (but slightly lower in the IMTA dimension) were higher in the control group, while intrinsic motivation was higher in the BBTA group.

The results of Gaussian distribution analysis of the samples are shown in Table 3.

Table 3: Kurtosis-Symmetry (K-S) and Shapiro-Wilk (S-W) normality tests of both samples, T-test (parametric) / U Mann-Whitney test (non parametric), p-values

	BBTA method		Classic method		T test	U Mann-Whitney test
	K-S	S-W	K-S	S-W		
IMTK	.092	.271	.044	.104	.061	
IMES	.685	.292	.201	.373	.268	
IMTA	.765	.625	.008	.124	.886	
AMOT	.000	.000	.000	.002		.636
EMER	.025	.095	.000	.000		.000
EMID	.012	.084	.000	.000		.038
EMIN	.289	.117	.057	.118	.001	

All extrinsic motivations were higher in the classic method group and were statistically significant in all dimensions.
Men samples results are shown in Table 4.

Table 4: Direct scores of men samples

	BBTA method		CLASSIC method	
	MEAN	SD	MEAN	SD
IMTK	5.2917	1.02382	5.1389	1.22830
IMES	4.2569	1.23850	4.1458	1.32742
IMTA	4.7083	1.18999	4.8056	1.23072
AMOT	1.5972	.96228	1.8403	.97129
EMER	5.2361	1.46134	5.5278	1.40887
EMID	5.7569	.87114	5.8056	.96937
EMIN	4.0208	1.35801	4.4167	1.32153

At first sight, we have the same conclusions: amotivation and extrinsic motivations (but slightly lower IMTA again) are higher in the classic method group, while intrinsic motivations are higher in the BBTA group.

Women samples results are shown in Table 5.

Table 5: Direct scores of Women Samples

	BBTA method		CLASSIC method	
	MEAN	SD	MEAN	SD
IMTK	5.7500	.93750	5.1742	1.18665
IMES	4.6288	1.14414	4.2727	1.08499
IMTA	5.3636	1.00018	5.3182	1.19614
AMOT	1.6288	.81997	1.5682	.77629
EMER	4.5606	1.31255	5.8106	.98033
EMID	5.7424	.98323	6.2727	.68284
EMIN	4.3333	1.42064	5.1364	1.07727

In the female samples, extrinsic motivation was higher in the classic method group, while amotivation and intrinsic motivation were higher in the BBTA group.

Because of the size of the samples, analysis of kurtosis and symmetry is required to verify the quality of the data, corresponding to Table 6 (men) and Table 7 (women).

Table 6: Kurtosis-Symmetry (K-S) and Shapiro-Wilk (S-W) normality tests of men samples, T-test (parametric) / U Mann-Whitney test (non parametric), p-values

	BBTA method		Classic method		T test	U Mann-Whitney test
	K-S	S-W	K-S	S-W		
IMTK	.629	.251	.045	.001	.568	.950
IMES	.448	.754	.360	.265	.715	
IMTA	.616	.780	.284	.161	.734	
AMOT	.000	.000	.041	.000		.311
EMER	.085	.001	.003	.000		.360
EMID	.414	.484	.008	.001	.824	.549
EMIN	.196	.472	.475	.348	.214	

In the male samples, kurtosis and symmetry showed appropriate values, and the difference was not statistically significant.

Table 7: Kurtosis-Symmetry (K-S) and Shapiro-Wilk (S-W) normality tests of women samples, T-test (parametric) / U Mann-Whitney test (non parametric), p-values

	BBTA method		Classic method		T test	U Mann-Whitney test
	K-S	S-W	K-S	S-W		
IMTK	.142	.092	.077	.368	.032	.950
IMES	.282	.241	.856	.626	.199	
IMTA	.814	.893	.198	.051	.868	
AMOT	.046	.000	.005	.000		.686
EMER	.328	.293	.008	.000	.000	.000
EMID	.087	.051	.013	.000	.013	.019
EMIN	.619	.620	.278	.522	.012	

In female samples, kurtosis and symmetry also show appropriate values, but the difference in the intrinsic motivation to know (IMTK) and the extrinsic motivation for external regulation (EMER) are statistically significant.

Discussion

In the present study, the number of women (47,8%) was very similar to that of men (52,2%), and the results are in agreement with those of Maries and Wulff. Parity allowed women to improve their results.

As shown, the BBTA group has the same lack of motivation (amotivation), but extrinsic motivation is higher in the classic method group in all three dimensions. BBTA students tend to experience less pressure from marks, teachers, or parents. They really enjoy learning the subject, as IMTK is very close to being statistically significant. This was not statistically significant, probably because of the sample size.

The BBTA group showed lower self-esteem than the classic method group (p=0.000) on the Rosenberg Self-Esteem Scale. Even though BBTA students had lower self-esteem than the classic group, they wanted to learn physics.

External pressures were not so important for the BBTA group, but were important for the classic method students. In the control sample, the students have stronger feelings like "I have to…,", "I must study because it is good for my future" and they also have a greater sense of threats. Here, we follow the description by Núñez et al. (2005) for the different dimensions of the AMS [32].

In the IMTK dimension, BBTA students are interested in knowledge and want to learn because it is something important for them and attractive. This implied that they were engaged in physics.

There were no significant differences in the EMES and IMTA dimensions, there is no significant differences between the groups. All students had the same level of motivation for the challenges and satisfaction to accomplish.

Analyzing the results by gender, men from the BBTA group had lower extrinsic motivations, higher intrinsic motivation to experience stimulation (IMES), and higher intrinsic motivation to know (IMTK), but this was not statistically significant. Therefore, it is necessary to use larger samples to obtain more reliable results.

For women, the sample size was large enough to obtain reliable results. Amotivation was similar in both groups. Intrinsic motivation to know was higher in the BBTA group (statistically significant). The BBTA women group showed lower self-esteem compared to the classic method group (p = 0.030) on the Rosenberg Self-Esteem Scale. However, extrinsic motivations were higher in the classic group in all three dimensions (EMER, EMID and EMIN). The differences were statistically significant.

All intrinsic motivation dimensions were higher in women with BBTA. In the case of IMTK, the difference was statistically significant. They enjoy learning, even though their self-esteem is low. They are growing up, maturing, and becoming involved with themselves through the subject. Using contextualized real-life problems as a tool for approaching the subject to female students not only works in mathematics, but also in physics, in light of the results of this study [33].

Women engage in the learning process when studying physics. They are especially motivated and have a special interest in learning, just for the pleasure of knowing. This finding is especially interesting because we do not observe differences between men and women, as described in a study by Huguet and Régner, already mentioned, in which women performed poorly in a task when it was presented as a math challenge.

A possible explanation for these results is that women are more mature than men are in adolescence [34]. If women are motivated and feel that they can succeed, they will go further in their results. Although the results are very positive for men, women are usually more responsible and obtain better scores than men on average.

Teenagers look for comfort and pleasure prior to thinking about what is appropriate for them due to the developing connections between the prefrontal cortex and limbic system [35]. The limbic system undergoes a first-like-unlike reaction. Students need stimulating classes to reinforce their desire to study and the rewarding mechanisms triggered by dopamine in the nucleus accumbens [36]. If the students just do not like whatever they have to learn, it is more difficult for them to achieve new knowledge.

The success of the method is probably because students are involved in their own learning process and establish their own path to acquire knowledge, according to their personal abilities. They like what they are learning, because it is possible to succeed. Intrinsic motivations are also apparent [37, 38].

Next step could be to implement this methodology for inclusive schools in future research. As this method mainly implies intrinsic motivations, it will probably offer good results as well. The main objective of this research is to learn about motivation, not the knowledge achieved. This could be another line of research to verify the good results obtained in different studies by Saleh, Tüfekçi, Worden, Hinton, and Fischer through BBTA methodologies.

Conclusion

In light of the results obtained, the BBTA group had fewer extrinsic motivations and more intrinsic motivations than the classic group, especially for the pleasure of learning. Women in the BBTA group showed a significantly higher interest in learning physics than women in the classic group. The application of the BBTA method is promising, especially for women involved in physics and science.

Conflict of Interest: There is no conflict of interest.

Ethics statement: Study and protocol approved by FIE (Fundación Internacional de Educación).

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