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# Fighting STEM Stereotypes in Adolescence: The Role of Spatial Skills, Identity, and Digital Interventions

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**Abstract**

Traditionally, formal education has favored boys, while girls, in the past, were relegated to the domestic sphere. This has been the case for centuries, without considering the possible specific cognitive needs of girls, which have been ignored. In Western countries, this has generated significant educational problems, especially in the learning of more technical subjects, with which girls not only do not identify but also often exclude themselves with the excuse that "it is not for them" (i.e., they tend to display a strong stereotype, a false belief, regarding these disciplines). The consequences have not been long in coming. Currently, in many Western countries, the low percentage of women in technical careers (such as Physics, Engineering, and Computer Science) is alarming. Is it possible to change stereotypes? This article addresses this complex issue, placing particular emphasis on the learning of spatial abilities, so important in all STEM careers (i.e., science, technology, engineering, and mathematics). This study concludes with examples of other stereotypes (mainly cultural) that have been eliminated or significantly reduced thanks to virtual reality (VR) and the help of artificial intelligence (AI). Could the same be achieved in the spatial domain?

**Keywords:** gender gap; spatial abilities; STEM disciplines; girls; adolescence; stereotypes; interventions; new technologies

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## 1. Introduction: The Current Situation

There are many academic skills that require considerable practice for students to develop them adequately [1,2]. Two of these, both crucial, are reading comprehension and spatial abilities (the latter now well recognized for their importance in the STEM disciplines—science, technology, engineering, and mathematics [3–5]). At least in Western countries, in the first case, reading comprehension, girls tend to be better than boys, while in the second case, spatial abilities, the opposite is true, as boys tend to be better than girls [1,6,7]. However, the time devoted to these skills in the school curriculum often varies greatly. Too much attention is paid to reading comprehension (which clearly benefits boys) and too little to spatial abilities (which clearly disadvantages girls). Spatial abilities probably contribute to important problems, such as the well-known gender gap in STEM careers (especially in PEC—Physics, Engineering, and Computer Science [8]), which so many countries are struggling to reduce or eliminate (for a review showing the importance of early intervention, see [9]). Multiple studies have shown that there are many variables that can influence these differences between boys and girls (sociocultural as well as biological variables) that become evident from a very early age, and several hypotheses have attempted to explain them. The most plausible one places the reason with our ancestors: their organization in hunter-gatherer societies has been decisive. Because of this, men excel in orientation and navigation skills, which are necessary for hunting, while women excel in limited space skills, related to food gathering and care of offspring. Let us bear in mind that our brains are practically identical to those of our ancestors who hunted and gathered [10,11]. Fortunately, it has been shown that spatial abilities can be learned, just like any other skill [5]. Moreover, it is relevant to note that traditionally, in boys' games, but not in girls' games, these abilities were often practiced, thus further increasing the imbalance between boys and girls in these skills. In fact, many authors consider the lack of childhood training of girls in spatial abilities to be one of the main reasons for their under-representation in STEM disciplines by the time they reach university in Western countries. What action be taken to remedy this situation?

It has been suggested [12] that since the school curriculum is already overloaded, it is important to consider other possibilities for practicing spatial abilities and spatial thinking, like 3D computer games and other extracurricular options, both in real life and virtually. Games have enormous learning power and those based on new technologies are especially important for the future. Many works have shown that a wide range of games (mainly 3D games presented in any format) can reduce gender differences in spatial cognition (for reviews, see [13,14]).

The present article addresses the beneficial effects that games and new technologies, such as the metaverse and artificial intelligence (AI), could have on the learning of spatial abilities during the critical stage of adolescence and pre-adolescence, which is the period in which the norms, values, motivations, and expectations of the society in which young people grow up are internalized. What do experts, especially women, think about the frequent gender gap in the spatial domain and in STEM careers?

## 2. The Importance of Expert Testimony and Examples of Three-Dimensional Geometry

Few testimonials are as impressive as the one given by Sheryl Sorby in her 2014 'TEDx' talk entitled *Recruiting Women to Science, Technology, Engineering and Mathematics* (https://www.youtube.com/watch?v=cJZIhl28HFI (accessed on 1 January 2020.)). In this lecture, Sorby explains with great frankness her successful passage through the various stages of her education, until she entered college and enrolled in engineering, a STEM career. It was then that, for the first time in her life, she had significant problems with a drawing subject in which she had to produce orthogonal projections (see Figure 1). She could not believe what was happening to her, especially since it was something that came easily to most of her male classmates. With effort, she was able to overcome this problem.

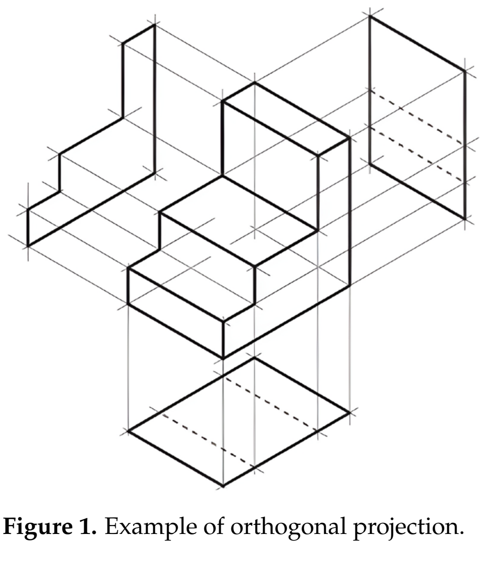

**Figure 1.** Example of orthogonal projection.

An orthogonal projection is a system of representation by which an object, which is in space, is drawn, or "projected", onto a plane or two planes [15]. Looking at Figure 1, given the elevation, profile, and plane of an object, one tries to mentally picture it in the three-dimensional object depicted in the center of the figure. In other words, one has moved from a two-dimensional representation (width and height) to a three-dimensional one (width, height and depth). Particularly useful for orthogonal projections is an ability that psychologists call spatial visualization, which is the ability to mentally represent, manipulate, and rotate objects in three dimensions.

The story of Sheryl Sorby, currently professor emeritus at Ohio State University, is exemplary, which makes her testimony especially valuable and enlightening. Her powerful lecture ends with practical advice for parents and educators about the activities and toys that suit their children (especially those that suit their daughters): encourage architectural games with blocks; involve girls in practical spatial tasks; manipulate, build, and draw 3D objects; play 3D video games; and use maps, not GPS, on field trips. Just as important, according to her, is to always keep in mind the power of expectations and tell girls that they can learn these skills just like they learn anything else. Sorby has devoted much of her professional life to developing and testing teaching materials (for a few examples, see [16–19]) to help students develop spatial abilities, especially future female engineers. Her excellent exercises aimed at developing spatial visualization and mental rotation are particularly noteworthy [19].

Indeed, many authors have pointed out the problems that geometry, especially three-dimensional geometry, sometimes poses to some students due to its abstract nature. Understanding its concepts and its three-dimensional (3D) space can be a difficult subject, requiring a lot of imagination on their part. Fortunately, new technologies have been shown to greatly facilitate this learning. Specifically, augmented reality (AR) is useful, because it enables interactive visualizations that make this kind of learning more accessible. As AR allows students to interact with 3D geometric shapes in real time and within their physical environments, it offers a more immersive and engaging learning experience than more traditional methods [20–23]. These studies show that AR is especially appropriate in teaching geometry, as it encourages students to connect between 2D and 3D objects and improves their spatial visualization skills, as well as motivating them.

It is worth noting the efforts that some Asian countries have made to make STEM disciplines part of their primary and secondary education curricula. For example, in Vietnam, this approach has been recommended since 2018, with the integration of multiple courses, as well as other tools, in schools for both students and teachers [24]. It is, therefore, not surprising that the gender gap in some Asian countries is disappearing or nonexistent. It would be wise to follow this example in Western countries, where this gap is so pronounced and is even currently increasing, further contributing to the persistence of undesirable stereotypes (see Section 4, Fighting STEM stereotypes in adolescence).

## 3. Spatial Abilities and Mental Rotation Tests

Spatial abilities play an important role in many aspects of STEM learning [25]. They are involved in multiple cognitive and behavioral activities and include a wide range of tasks (from paper-and-pencil tests to real-world navigation). But, unfortunately, there is no agreement among researchers on either the number or the way to measure them. This implies that there is no orderly account of the available material that could help teachers, in their work, to assess possible problems [26]. Despite the existing differences between the different spatial tasks, it has been found that they are often correlated, so improvement in one spatial task positively affects the others [5]. In Western countries, in general, boys outperform girls in these abilities and the differences increase with age, to the detriment of girls (for several monographs with numerous examples, see [27–32]). However, this is not the case in other countries, where girls may equal or surpass boys in spatial abilities and STEM disciplines [1,6,7].

The most common methods to measure spatial abilities are mental rotation tests, the measurement of which became popular in the 1970s [33–35], especially the speed of mental rotation. There are numerous variations of these tests. Figure 2 (the Mental Rotation Test (MR)) and Figure 3 (the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R)) present two frequent examples. In Figure 2 [33], there is a target figure in the left position, followed by four choice figures. The task is to indicate which two of the four choice figures are rotated reproductions of the figure on the left. The correct answers are the first and the third (starting from the left).

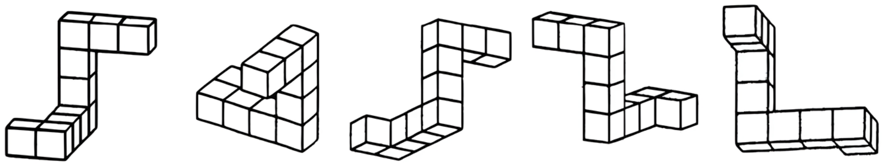

**Figure 2.** Mental Rotation Test [33].

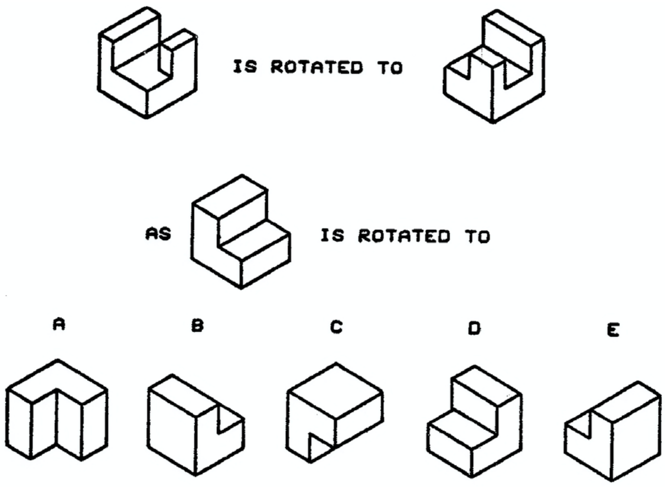


**Figure 3.** The Purdue Spatial Visualization Test [34]. At the bottom row, only drawing D meets the required rotation.

In Figure 3 [34], first, you have to determine how the object on the top line of the figure rotates. Then, looking at the object in the middle line, you have to imagine how this object looks when rotated exactly like the one in the top line. Finally, looking at the bottom line, you have to choose one object from the five presented on this line. Only drawing D fulfills the rotation required.

It is in these tests, mental rotation tests, that the largest gender differences have been observed, even at very early ages [36]. However, it is striking that when the time factor is removed, the performance differences between men and women tend to disappear [37,38]. This has led to open questioning of these tests, as they appear to involve factors other than mental rotation, like cultural differences, educational background, and individual cognitive styles ([39,40]; for a critical review, see [41]). For a selection of studies showing clear beneficial effects in spatial tasks after MR, see Table 1 (references [42–51]). In summary, although these mental rotation tests are still considered particularly useful for measuring spatial visualization, it is now openly acknowledged that they need to be revised to take into account the various factors that influence them.

**Table 1.** Some studies in the spatial domain that show improvements after mental rotation (MR) and other beneficial effects of MR.

| Case Study | Learner's Age | Region | Teaching Objectives | Application Procedure |
| --- | --- | --- | --- | --- |
| Hawes et al., 2015 [42] (n = 61) | 6–8 | Canada | Investigate the malleability of children's spatial thinking | 6-week period |
| Lowrie et al., 2021 [43] (n = 876) | 12–14 | Australia | Effects of spatial training on spatial reasoning and mathematics | 12 h |
| Gilligan et al., 2020 [44] (n = 250) | 8 | UK | Transfer of spatial training | 7-month period |
| VanMeerten et al., 2019 [45] (n = 140) | 11–14 | USA | Mental rotation skills and performance in a 3D puzzle game | 3 sessions of 50 min. |
| David, 2012 [46] (n = 178) | Approx. 14 | Romania | Benefits of spatial skills training through computer games | At least six h |
| Meneghetti et al., 2017 [47] (n = 72 females) | Approx. 20 | Italy | Mental rotation training and transfer effects | 6 sessions of 45 min. |
| Terlecki et al., 2008 [48] (n = 1300) | 17–44 | USA | Effects of videogame training to other spatial tasks | Approx. 3 semesters |
| Guillot et al., 2007 [49] (n = 184) | Approx. 19 | France | Relationships between visuospatial representation, mental imagery, MR, and functional anatomy | (not specified) |
| Moen et al., 2020 [50] (n = 36) | Approx. 19 | USA | Training mental rotation for improvements in STEM disciplines | 10 sessions |
| Dong et al., 2025 [51] (n = 34) | Approx. 24 | China | Long-term effects of combining different techniques with MR training on both behavioral and neurophysiological measures | 10-day training phase |

## 4. Fighting STEM Stereotypes in Adolescence

Adolescence, which roughly covers the period between the ages of 10 and 18, has often been described as a time of 'storm and stress', a time of change, renewal and growth, when problems come to a head. The reasons for this have ranged from developmental considerations to hormones and accumulated life stresses [52–54]. During adolescence, boys and girls need, above all, to define their identity, which must be coherent with their abilities and desires. Adolescence is a period in which young people discover how they want to direct their lives and where boys and girls appear to be less dependent on their parents, while their dependence on and intimacy with friends and "influencers" increases. At this stage of maturation, social rewards (such as congratulations for a task well done) are very important, as it is critical for young people, who are very impulsive and sensitive, not to experience social rejection. Moreover, the opinion of one's close group of friends is crucial. This is known as "groupism" [53]. It will be difficult to change a teenager's mind if the close friendship group does not do so [54,55]. This susceptibility to group influence and social influence in general decreases with age [56]. Likewise, the impact of influencers, especially that of online social platforms, is currently worrying, as it can affect their mental health and well-being. In fact, both positive and negative effects have been observed [57].

Multiple studies have addressed the issue of gender equality at this stage of life, where it is crucial to challenge deeply entrenched gender roles such as attitudes and false beliefs or stereotypes. A typical example relates to career options, which perpetuate a gender gap in which girls are more likely to go into traditionally female fields such as health, primary education, and domestic (HEED) roles, while boys are attracted to traditionally male domains such as science, technology, engineering, and mathematics (STEM) [58–62]. This is particularly surprising given that girls' mathematical performance is often higher than that of boys, although they display lower self-esteem and self-efficacy [63].

Today, it is known that spatial and mathematical abilities are deeply related, as well as that both can be fostered through practice. In the PISA reports, Space and Shape is a component of 'Mathematical Literacy', and its contents are spatial in nature (such as geometry, spatial visualization, measurement, and algebra). The results in the PISA reports [6,7] (see also [1]) show a large discrepancy between countries for this section of mathematics. In Western countries, boys tend to perform better than girls in Space and Shape areas in adolescence. What are the reasons for these differences? Recent work suggests that this gender gap in STEM studies begins to consolidate in adolescence, with boys having clearly better spatial abilities. Specifically, ref. [62] showed that spatial abilities around the age of 15 could predict STEM career choice at university (after accounting for multiple cognitive and motivational mechanisms). However, other authors emphasize the importance of the different preferences observed in adolescents. Girls prefer career options that involve working with other people, while boys are more inclined towards jobs that involve working with things [64,65]—this favors more technical options (such as PEC careers). In addition, it has been openly stated that, at least in part, it is a question of mindset, which is often reproduced at home, in advertising, and in marketing [66]. This mindset has been shown to influence not only young people's future career choices but also the scores that they achieve in different subjects during primary and secondary school, depending on whether the subjects are seen as more or less masculine or feminine. For example, in the sentence "mathematics and science are things of men", the stereotype that mathematics and science require 'masculine' skills is present, leading to a feeling of 'not belonging' in girls, which alienates them from these subjects (for an excellent recent review, see [67]). In this respect, it has also been found that boys tend to manifest more positive attitudes towards the study of science, technology, engineering, and mathematics, while girls manifest lower self-confidence and self-efficacy, which is not normally observed in childhood [63]. Undoubtedly, in Western countries, several factors must be contributing to the gender gap in STEM studies (especially in PEC careers).

Although stereotypes can be observed even in early childhood [68,69] and changing them is no easy task, fortunately, there are interventions that can go a long way towards correcting them. Because the most critical period for identity exploration is the pre-adolescent stage (approximately 9–12 years old), where self-concept and stereotypes become most important, working on mathematical and spatial abilities with girls in this complex period is crucial [70]. To this end, multiple interventions have been carried out for increasing girls' self-esteem and low mathematical self-concept, as well as to reduce anxiety problems, like spatial anxiety [71–73].

In addition, other interventions have been shown to have a positive effect on reducing STEM stereotypes. For example, in work with boys, some interventions have demonstrated a change in stereotypes, at least in the short and medium term, by counteracting negative messages about girls' STEM skills [74]. But as it is difficult to sustain these changes in the long term, the appropriateness of these interventions has been questioned. Indeed, a review of this topic [75] has emphasized the lack of longitudinal studies, which would be so important for understanding the complexity of factors hindering girls' participation in STEM fields (for an exception, see [76], which also addresses important race/ethnicity issues). It is worth highlighting a recent study [77] that emphasizes the importance of the first year of schooling as the time and place when a gender gap in mathematics emerges in favor of boys. According to the authors, this helps to focus the search for early interventions. What other approaches might help to reduce stereotypes in the long term at these difficult ages?

## 5. Could New Technologies Counter Stereotypes and Close the Gender Gap in STEM Careers?

In the previous sections, the problems of insecurity and low self-esteem in the spatial domain that often accompany Western pre-adolescent and adolescent girls were mentioned. It is a period in which many girls exclude themselves from STEM careers, in particular from PECS (Physics, Engineering, and Computer Science), often using the excuse that these are not careers "for them." This is where new technologies could be of enormous help. For example, using AR, a way, albeit indirect, to combat these stereotypes would be through a hypothetical game, in which the adolescent girls would adopt the role of a researcher. The participants, whom they would have to search for, would be elementary school children, preferably young girls. This game, which would be simple and easy for the girls to play on their cell phones, would be based on the research conducted by Rossano et al. [78] (see this work for all technical details). The objective would be to promote the learning of geometry through experience with solid figures, specifically polyhedral solids (cubes, pyramids, and parallelepipeds). Once ten participants had been recruited, they would carry out, each of them individually, first, a Pre-test; second, an "intervention"; third, a Post-test; and fourth, with the results of all the participants, a statistical analysis comparing the Pre-test with the Post-test; and, finally, each researcher would individually give her participants a short satisfaction questionnaire regarding the intervention phase. Let us see the characteristics of each phase of the game:

1. *Pre-test*. One by one, each solid is chosen by the participant, who has to say how many faces that figure contains;
2. *Intervention or Test*. One by one, each participant chooses the different solids, which, using zoom in and zoom out, they will be able to rotate and pause if necessary to see all the details of the figures (it is crucial to count the number of faces, the number of vertices, and the number of edges, as well as to recognize the shape of each face and polygon);
3. *Post-test*. As in Pre-test stage, each solid is chosen by the participant, who has to say how many faces that figure contains;
4. *Statistical analysis*. The program used saves the results of all participants in the *Pre-test* and *Post-test* phases and performs a $t$-test on these scores, showing the researchers whether there is improvement between both tests and whether the difference is statistically significant;
5. *Satisfaction questionnaire*. One by one, each participant indicates, on a scale of 1 to 10, how they rate the intervention phase (i.e., whether they liked this phase).

It is expected that the little girls will have improved between the *Pre-* and *Post-test* phases and that this will also be reflected in their scores of the questionnaire. Therefore, the adolescents, acting as researchers, will be able to see the importance of experimenting with these complex solids, which will undoubtedly make them reflect on the possible reasons for their stereotypes (i.e., lack of experience).

New technologies could also be of enormous help thanks to intercultural exchange. In fact, international exchanges and cooperation have become common with the rise of globalization. For instance, today, there are VR/AR/MR networks, as well as other technical developments, that can be particularly appropriate when used during these years to overcome these false beliefs. These networks allow for agile communication and collaboration on a global scale and could, with the help of a simultaneous translator, contribute to overcoming stereotypes in Western countries. The reason for this lies in the importance of face-to-face communication with colleagues of the same age, i.e., with girls from other countries in which they are the ones outperforming boys in the Space and Shape section of the PISA [6,7] reports (i.e., girls outperforming boys in STEM disciplines). This experience may initially cause them to experience what is called cognitive dissonance [79], a psychological discomfort, as what they will see and hear will be the opposite of their own beliefs and stereotypes. That unpleasant feeling will be the beginning of change. If girls from Western countries could easily converse and interact with their peers from these other countries and then discuss these experiences with each other, as a group, they would probably not only be very surprised, but they would also come to accept that they have false beliefs. In this experience, the teacher's intervention could be crucial for arbitrating the dialogue between the two sides, encouraging deep reflection, thus fostering debate, with its many nuances, and critically assessing and analyzing different opinions. In this 'adventure', greater parental involvement would be advisable [80], as parents could give their daughters confidence not only to change their minds but also to increase their self-esteem.

Recent studies [81–85] on cultural stereotypes and intercultural competence show that this is not only possible but that the results can be very good. Most of this work is supported by interactive 360-degree video technology together with AI—an artificial intelligence-based translation tool. For example, in [83], which addressed cross-cultural stereotypes between Chinese and Indonesian students, simultaneous and interactive multi-user interaction was achieved. The results showed a clear reduction in stereotypes. The authors highlighted the effectiveness of this intercultural learning activity in redefining students' cultural perspectives. In it, 360-degree video technology proved to be a practical and easy-to-use medium for intercultural education. These findings provide an important benchmark for addressing other types of stereotypes through virtual reality and new technologies, such as AI. Is our technology ready to make this a widespread and low-cost reality in the spatial domain, aiming to overcome the problems of stereotyping of girls in Western countries, and are parents and educators ready for this change?

## 6. Discussion

In this article, we have focused on understanding sex and gender differences in primary and secondary education with respect to spatial abilities, which are so important in all STEM disciplines, especially in PEC careers. A review of the literature shows that educational researchers have often overlooked several factors related to the interaction between our developmental history, cultural and occupational gender norms, and girls' desire to study or pursue certain subjects, among other things. This statement leads to the conclusion that the educational system, at least in Western countries, must consider not only gender equality in childhood and adolescence but also the different needs that these students may have. This is a goal that has not yet been achieved! The differences between boys and girls in the spatial domain, traditionally ignored, must be recognized and addressed (both inside and outside of school) if we truly want all students to have the same opportunities when they reach university.

Humans live in an environment full of stimuli, but the brain can only process a few of them. What do we pay attention to when solving spatial tasks? It should be kept in mind that without attention, other more complex processes, such as learning and memory, cannot take place. Are there differences between men and women in this regard? It has been shown that when solving a spatial task that allows for multiple solutions (like one spatial and one non-spatial), men and women tend to solve the task differently (this also occurs in other mammals). Males seem more likely to use geometric information (such as angles, cardinal points, and distances), while females tend to use landmarks (which are prominent objects: a specific building, a sculpture, a park, etc.). Therefore, in men, we speak of orientation or Euclidean strategies (which are hippocampal-dependent navigation strategies), and in women, we speak of topographical or landmark-based strategies (which are non-hippocampal strategies, mainly based on the caudate nucleus). Thus, different brain regions seem to support different ways of solving spatial tasks. This could be a recollection of our hunter-gatherer past, which has generated different predispositions or preferences in men and women [11,86]. But, today, we know that these different preferences or predispositions are not fixed but highly malleable [5], as is the brain, due to experience, especially in childhood and adolescence [87–89].

Whatever the reason for the differences between boys and girls (and men and women) in solving spatial tasks, there are well-controlled studies that demonstrate them. To what extent does it matter if males and females use different strategies to solve spatial tasks if they solve them correctly? Are some navigation strategies better than others? Recent research shows that the answer to this question is yes: some navigation strategies seem to be more beneficial than others. Let us look at an example related to Alzheimer's disease (AD), which is much more common in women than in men. In fact, women account for two-thirds of AD cases [90–93]. It has been shown [94–96] that the spatial problem-solving and navigational strategies that both men and women use more frequently may be crucial in both the propensity for developing AD and the ability to slow its development once it has appeared. Today, it is known that a well-developed hippocampus helps to prevent Alzheimer's disease. There is evidence [95] that the continued use of hippocampal-dependent navigation strategies (in the case of men) increases hippocampal grey matter, while, in contrast, when using non-hippocampal-dependent strategies, such as the caudate nucleus (in the case of women), the gray matter of this structure increases at the expense of that of the hippocampus—that is, the gray matter of the hippocampus decreases. Consequently, it was argued [96,97] that a reduced hippocampus may be one of the reasons for the high incidence of women with AD.

Given the brain's malleability, especially in childhood and adolescence, the previous example highlights the importance of girls practicing hippocampal-dependent spatial tasks and navigation strategies, which will also have other consequences, such as narrowing the gender gap in STEM disciplines. Future research will need to clarify many unresolved issues, emphasizing the importance of early intervention.

## 7. Conclusions

Early intervention and women who serve as good role models are crucial to eradicate the gender gap in STEM disciplines, which is so pronounced in adolescence, although with important changes depending on race/ethnicity. Efforts are required in this regard. Game-based digital learning interventions are a possible solution. These games can be fun and highly motivating. Most importantly, the opportunity for adolescent girls to communicate directly with their peers in other countries where this gender gap does not exist seems crucial. This type of intervention, free and accessible to all, is urgently needed. The future of our young women is at stake! The purpose of this article has been to make this request to the relevant scientific community.

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