THE PHANTOM MENACE: SPATIAL ABILITIES AND STEM OUTREACH TO FIGHT UNDERREPRESENTATION IN STEM (CONCEPT)

M. Velho [1]
Technological University of Dublin
Dublin, Ireland
ORCID: 0000-0002-7872-0054

D. Dorran
Technological University of Dublin
Dublin, Ireland
ORCID: 0000-0001-5469-0658

G. Duffy
Technological University of Dublin
Dublin, Ireland
ORCID: 0000-0003-3049-7030

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ABSTRACT

Spatial abilities are an important, and often overlooked, component of Science, Technology, Engineering and Mathematics (STEM) education with skills like spatial visualisation and mental rotation being important for technical professions such as engineering. Individual differences in spatial abilities have been reported throughout the years. Factors such as being female or having a low-socioeconomic status are linked with lower spatial abilities level. Spatial abilities training interventions have proven to be effective, with some showing improvements, not only in spatial abilities level, but also in the success and retention of students enrolled on STEM degree

[1] *M. Velho. E-mail: mariana.velho@tudublin.ie*

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programmes, especially for women. In todays' technological society, STEM outreach activities are a common method to promote STEM for children, showing them role models in the area, and improving their self-efficacy, sense of belonging and motivation to follow careers in STEM. At the same time, the underrepresentation seen in the area (e.g., women; LGBTQ+ community; ethnic minorities; and other marginalised groups) needs to be addressed in order to enhance the inclusive environment of these fields. This concept paper discusses review work in relation to underrepresented groups and how future spatial abilities studies should consider integrating the knowledge from past spatial abilities studies into STEM outreach activities. This integration can make spatial training available to more people, revealing itself to be a useful tool in helping diminish underrepresentation in STEM.

1 INTRODUCTION

When considering a career path in STEM, different factors influence someone's decision to follow that path. Not everyone starts their career path from the same position and there is a lack of representation and role models in STEM fields (e.g., visually impaired people, women, ethnic minorities, LGBTQ+ community, low-socioeconomic status, etc.) [1] and being from an underrepresented group can deter someone from following a STEM career. Underrepresentation can lead to a lack of role models in the area – making people from underrepresented groups feel like they don't belong in STEM and particularly vulnerable to dropout of STEM programs [2].

When promoting STEM as a career path, the focus tends to be placed on building a sense of belonging and self-efficacy in the area. However, spatial abilities level [3] has been shown to be another extremely important and influencing aspect which has been identified as a sleeping giant – or a phantom menace – that helps identify and develop talent in STEM domains.

Spatial abilities training programs have proved to be effective not only in improving participants spatial abilities level but also in maintaining participants in STEM degrees, especially women [4]. However, these programs are usually implemented in classroom settings. STEM outreach activities and programs are a common way to showcase STEM career paths to a variety of audiences through different delivery methods, delivered in different environments and communicating a range of scientific disciplines.

Adapting spatial abilities training tasks into STEM outreach programs that are designed for a wider audience can make spatial abilities training more accessible, allowing more people benefit from it. This paper suggests how existing outreach programmes can be adapted to improve the starting position for underrepresented populations on their journey to a successful STEM career.

1.1 Spatial abilities, STEM education and individual differences

In our daily lives, when packing a suitcase, organising objects, exploring around a city, describing where a place is, or the relation between two objects, there is a set of skills common to these tasks: spatial abilities. Spatial abilities can be defined as the performance of tasks that require (a) the mental rotation of objects; (b) the ability to understand how objects appear in different positions (i.e., if we move and look to the object from different positions); and (c) the ability to conceptualize how objects relate to each other in space [5]. They have been shown to play an important role at least in 84 different careers [6] and having 3D spatial skills are critical to success in a variety of careers, including engineering [7]. Spatial abilities are also correlated with students' achievement in STEM domains [8] [9] [10] and can predict the likelihood of students pursuing, majoring, and persisting in STEM careers [8] [11] [12]. There is a strong relation between spatial abilities and STEM performance, at all levels of expertise, because spatial abilities either limit or enhance whether a person is able to perform the kinds of spatial thinking that seem to characterize STEM thinking [12].

Within spatial abilities, mental rotation exercises are among the cognitive tasks for which the largest gender differences, in favour of men, is found [13]. Factors that have been shown to influence gender differences are stereotyping, gender role identity, socioeconomic status, and strategy selection. However, it is important to state that the majority of past studies about gender differences in spatial abilities collected and focused on gender with a binary lens, or don't state clearly how sociodemographic data regarding gender was collected and analysed (e.g., non-binary data actually being collected but not included in the analysis since that data didn't fit in the study aim). Future studies should encourage a more inclusive change on how gender or sex is studied and reported, even if gender is not a main factor in the research and it is only for demographic reporting. A researcher that is not studying gender explicitly, still has an ethical and scientific obligation to describe the demographic characteristics of their sample so that other scientists can evaluate the representativeness, inclusivity, and generalizability of the research [14].

1.2 Past spatial training studies

Recent research findings indicate that spatial abilities aren't as immutable as many people may have been led to believe [15]. Meaning that spatial abilities aren't a static skill which we are born with and can't be improved. Spatial abilities are malleable, and some forms of training can even endure and transfer to other skills. This ability can be learned and trained, with an overall size effect of training of 0.47 standard deviations, according to a meta-analysis with the result of over 200 studies on spatial training [16]. Considering what was already stated about the role that spatial abilities play in STEM education and in following STEM careers, knowing that they are malleable, gives us a window of opportunity to put this knowledge into use and help keep underrepresented minorities in STEM paths by giving them the required training in the area. Students with lower spatial abilities levels will be therefore be better supported and reduce the likelihood of them dropping out of STEM paths.

Previous studies on spatial abilities training showed that besides improving students' spatial abilities performance, training one spatial ability construct can lead to improvements in other constructs not included in the intervention programme [17]. Besides, it showed that different activities, durations, modalities (paper-based, digital-bases, or both), environments (classroom setting or not), and pre- and post-test timings, are important variables to take into consideration when developing an intervention that aims to train and improve spatial abilities.

1.3 STEM outreach: a tool for accessible spatial training

STEM outreach can be considered "the act of delivering STEM content outside of the traditional student/teacher relationship to STEM stakeholders (students, parents, teachers, etc) in order to support and increase the understanding, awareness, and interest in STEM disciplines" [18]. It provides a unique platform to reach students of all grade levels and ages, using different delivery methods (lectures; active learning problem-based learning; workshops; camps & events) and communicating different scientific areas (e.g., biology; chemistry; engineering; physics).

However, the majority of STEM outreach activities are developed with the aim to communicate a scientific concept and making science fun and accessible to everyone. This means that usually the spatial abilities dimension, or the spatial ability level of the audience, is not taken into consideration when developing an activity. STEM outreach activities that can train or develop spatial dimensions usually do it "by accident". For example, in a STEM outreach activity developed to communicate and show the work engineers do, participants are required to model the engineering design process making blueprints of their cities and create replica models showing a block of their cities using all recyclable materials. Preparing a blueprint can make participants visualise and sketch their design and, by transferring the design from paper to three dimensions, they are making a connection from 2-D to 3-D promoting spatial thinking [19].

1.4 The importance of an intersectional framework

When taking into consideration the integration of spatial tasks into STEM outreach activities, underrepresented populations must be acknowledged, with the focus changing from reducing the bias to promoting inclusive behaviours [20]. In order to adapt these tasks, previous knowledge from past spatial abilities studies should be considered as well as the knowledge on how STEM outreach activities have been made more inclusive. For example, simple gestures such as looking to those tasks used in past spatial abilities training interventions, with sighted individuals, and adapt them with the use of textures (sandpaper; Braille; etc) or haptic screens, making them more suitable for sight-impaired individuals. Or, for example, by including scientists from these different underrepresented groups presenting the scientific concepts to the audience, making the majority of people feel included by seeing all those different role models.

Spatial abilities has an important role in following a STEM career and past spatial trainings have shown that they can help keeping people in STEM degrees. However, we can't think that training someone's spatial abilities is enough to motivate them to follow a career in STEM. When adapting and integrating this training to open them to more people we must do it considering all the factors that can play a role and might interfere with the positive results of spatial training. Looking at integrating spatial abilities training tasks within STEM outreach activities considering an intersectional framework that acknowledges that each person's individual characteristics (e.g., gender, race, physical ability) overlaps with one another and affects their status in the world is essential.

2. FUTURE DIRECTIONS

Considering the previous topics, and brief literature review, we can see that there is a line of study that should focus on how spatial abilities and STEM outreach activities interact, acknowledging from the beginning that when developing STEM outreach activities spatial abilities should be taken into consideration. This integration of spatial abilities into STEM outreach can prove to be a valuable tool in improving underrepresentation in STEM fields by getting STEM concepts and spatial training closer to a wider audience. The following suggestions should be considered in future studies that aim to look into spatial abilities and STEM outreach programmes:

- ⇒ A more inclusive collection and reporting of data regarding gender. Provide participants more response options, reflecting the present knowledge we have of gender being a spectrum. Even if analysing only binary data, all the data should be reported, acknowledging the existence of those responses and why they were deleted from analysis (e.g., not enough data);
- ⇒ Always aim at making the activity the most welcoming and engaging for everyone. When developing STEM outreach activities always have an intersectional framework in mind, taking into consideration all the different characteristics of your audience and if they are being considered by the activity being developed. When facilitating a STEM outreach activity, we can be previously aware of some characteristics of our target audience, or not, but that doesn't mean we shouldn't previously think about them. For example, if we know the age range of our audience we will prepare the activity to fit that age range. But why not also consider that the audience is as diverse as it can be? And, for example, include role models of scientists that come from underrepresented groups and work on the STEM area that is being communicated. This will already allow the children from your audience that come from these underrepresented groups to have contact with a role model in the area. Or, when developing activities that have characters (e.g., games; books; etc.) have characters that represent these groups and show as much inclusion and diversity in STEM as possible.

When designing an activity that aims to be engaging to everyone, spatial abilities level should be taken into consideration. With the current knowledge we have on the relation between spatial abilities and STEM education, we must acknowledge that according to the audience spatial ability level they might find the activity harder. Although, for example, asking teachers, or parents, to pass some spatial abilities pre-test to the audience we are engaging with would be the perfect scenario so we can be aware of our audience spatial ability level, and adapt our activity accordingly. However, this is most of the times not possible. This doesn't mean that at least thinking about how this can have an effect in facilitating the activity shouldn't be considered. We know from past studies how spatial abilities level relate to some factors such as gender and socioeconomic level, by knowing the audience demographics this can help us adapt the activities accordingly. Another possibility is, by keeping always in mind that spatial abilities might affect the engagement of the audience with the activity and if having multiple outreach sessions with the same audience is possible, start with simpler spatial tasks and adapt them as the audience finds them easy or difficult. Furthermore, usually big science centers or STEM outreach facilities have a pre-defined catalog of STEM outreach activities from where they choose which ones to use, mainly according to the audience age range.

However, these centers should start considering the spatial abilities factor and think if the cataloging of these activities should also be done according to the spatial abilities level that they might require (e.g., are some activities more appropriate to an audience with a lower spatial abilities level?). By having these cataloging done these science centers could ask teachers to pre-test the kids before bringing them to an activity or – if that is not possible – and considering they have the resources, having spatial tests on tables or laptops ready to be filled by the audience before starting the activity with almost instant results (e.g., use of software such as Qualtrics ®) and choose the activity to be done with that audience accordingly to those results.

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