Enhancing Primary Teachers’ Spatial Ability to Improve Inclusive Math Learning: The MATABì Project

(Article begins on next page)

Enhancing Primary Teachers' Spatial Ability to Improve Inclusive Math Learning: The MATABì project

Maria Giulia Ballatore[1[0000-0002-6216-8939]], Barbara Romano[2[0000-0001-5097-7168]], and Anita Tabacco[1[0000-0001-5731-4885]]

[1] Dept. of Mathematical Science "G. Lagrange", Politecnico di Torino, Corso Duca degli Abruzzi 24 – 10129 Torino
[2] Fondazione Giovanni Agnelli, Via Giacosa, 38 – 10125 - Torino
maria.ballatore@polito.it

Abstract. This study examines the impact of Matabì training on primary teachers' spatial abilities and its potential for improving students' math learning and approaching the related gender gap. Knowing the correlation between spatial abilities and STEM learning, the research specifically focuses on the direct spatial training provided in two different editions of the course (face-to-face and online) and its effect on teachers' spatial skills. The findings indicate that approximately 70% of primary teachers demonstrated improved mental rotation ability after participating in the project. This enhancement in spatial ability equips teachers with the skills needed to effectively integrate spatial reasoning into their instructional practices, thereby facilitating students' comprehension of geometric concepts, problem-solving skills, and spatial visualisation. Moreover, alongside the direct training, the Matabì course empowers teachers' confidence in teaching mathematics by incorporating constructional play and using students' individual LEGO Duplo kits to support their mathematical understanding. The findings underscore the potential of the Matabì project, as it contributes to teachers' professional development while promoting effective and inclusive mathematics education. By increasing awareness of spatial thinking and addressing teachers' training needs, the Matabì project emerges as a valuable initiative in mathematics education.

Keywords: Spatial ability, Gender gap, Math education, Constructional play, Primary teacher training.

1 Introduction

The challenge of learning mathematics in Italy is particularly pronounced, especially for female students. Gender disparities in math test scores emerge early in schooling and continue to widen as students' progress through grades. Understanding the underlying causes of these disparities requires examining the differences in experiences and expectations between boys and girls [1, 2]. Environmental influences and early-life experiences are crucial in shaping children's cognitive development, leading to variations in access to diverse developmental opportunities and contributing to gender inequalities in mathematics [3].

Research suggests that gender-specific beliefs and behaviours regarding toy suitability, as well as disparities in exposure to specific learning experiences, contribute to the gender gap in mathematics. Boys often benefit from more opportunities to engage with toys and activities that facilitate learning in STEM, resulting in greater self-confidence and reduced anxiety, which can impact educational outcomes [4, 5].

Historically, spatial ability has been associated with success in STEM fields, making it a crucial factor for individuals aspiring to pursue careers in engineering, science, drafting, designing, and related disciplines [6]. However, a significant gender gap has been observed in this cognitive domain. Robust gender differences exist in spatial ability, with males generally outperforming females on certain spatial tasks, particularly those related to mental rotation [7].

Addressing these challenges, in May 2022, we started the design of the Matabì project (www.matabi.it). It was developed by the Fondazione Agnelli in collaboration with the Politecnico di Torino and supported by Exor and The LEGO Foundation, with the aim to improve math learning and reduce gender disparities in Italy. This innovative educational project targets primary school teachers and students, providing them with a captivating and original learning experience. By enhancing spatial ability and reducing the gender gap through construction play using building toys, such as a dedicated LEGO Duplo kit, Matabì aims to help students grasp abstract concepts and alleviate math anxiety. Notably, the project recognises the need for more support in developing spatial skills during the early years for female students.

Matabì is a kit of 14 LEGO Duplo bricks of seven different colors and four shapes. A 10-hour teachers' training was designed to support the introduction of the kit in class, working on their own skills and confidence, and raising awareness of the gender gap. Additionally, three workshops are run in class with the support of tutors.

In line with Fondazione Agnelli's mission to rejuvenate education by directly involving teachers and enhancing their pivotal role through training opportunities, the Matabì project seeks to foster a culture of STEM innovation and sustainability from an early age. Its ultimate goals include making math learning more stimulating and effective for all students, supporting increased access for girls to higher levels of scientific education, and promoting their presence in scientific and technological communities. By empowering girls to pursue STEM education and careers, Matabì contributes to create a more inclusive and prosperous society where valuable resources are not squandered.

This paper focus on the Matabì purpose to enhance primary teachers' spatial ability as a means to improve math learning. The effectiveness and impact of this approach will be explored, shedding light on the potential of spatial skill development in promoting equitable math education for all students.

We begin by introducing the context of the Italian education system discussing the gender gap, and then go on to the research questions' details. The fourth section describes the methodology used in the study. Section 5 analyses the results of the Matabì training, followed by a discussion and general conclusions.

2 Context

In the Italian education system, children undergo a two-cycle education process. The first cycle spans eight years, from 6 to 14, while the second cycle lasts five years, from ages 14 to 19. Compulsory education is required from ages 6 to 16, typically encompassing the second year of upper secondary school. However, young individuals have the right to receive formal training until they turn 18, the legal age. Before compulsory schooling, children can attend nursery or kindergarten, until age 3. From ages 3 to 6, they can attend pre-school. At 6, students begin primary school, which lasts five years.

Every year in spring, national standardised tests in math, literacy and English are administered to students in the 2nd, 5th, 8th, 10th and 13th year of schooling by the INVALSI (Istituto Nazionale per la Valutazione del Sistema Educativo di Istruzione e di Formazione). Since the very first edition of the test in 2002, females' mathematics score was systematically lower than that of males and increased with the years of schooling. In grade 2 [8], the gap is small (but already noticeable), but in grade 5 [9], it is equivalent to one-half of a school year, and in grade 13 (the last year of high school), the average difference is about 7 points corresponding to what an average student learns in two-third of a school year. In technical institutes, the gap is 11 points, equivalent to more than one year of schooling.

What are the underlying causes of the gender gap? While no definitive reason exists, several plausible explanations can be considered. Neuroscientific research reveals no biological differences in brain structure between males and females at birth [10]. However, the brain's plasticity means that its development is influenced by the cultural and environmental factors that individuals are exposed to from birth onward [11]. Evidence demonstrates the crucial role of visual-spatial ability in developing quantitative reasoning skills [12]. Encouragingly, visuospatial thinking can be enhanced at almost any age, although earlier intervention yields more significant benefits [13].

Various factors contribute to this influence, including stimuli and conditioning from family, peers, teachers, training, and experiences starting from an early age [14]. Gender stereotypes, in particular, appear to play a significant role, leading individuals to believe that certain academic studies and professional careers are more suited to one gender over the other [15]. This study by Carlana demonstrates that teachers with stronger gender stereotypes can significantly impact their students' achievements. Gianini Belotti has studied the Italian picture and focuses on the crucial factor to be considered at an early age (the first six years of life). Her basic idea is to educate pupils, in its original meaning, "ex ducere" [16]. In this sense, great support for teachers are textbooks. Although they are full of gender bias [17].

Teachers' stereotypes demotivate girls, leading to lower math performance and less challenging educational paths. These effects are further compounded by a diminished sense of self-efficacy among girls taught by teachers with gender biases, particularly regarding their mathematical abilities [18].

Another line of research indicates that the perception of lower self-efficacy induces more significant anxiety, which exerts a decisive influence on test results and the ability to perform at one's best. Consequently, test scores may not fully account for the gender differences in mathematical skills [19].

3 Research questions

The impact of the Matabì project on students is currently studied through an ongoing Randomised Controlled Trial (RCT)[20]. The evaluation compares the effects of a treatment delivered in two ways (face-to-face and online) with a control group. Due to practical reasons, the RCT involves schools only in the city of Torino, Italy. However, the online edition also included teachers from other regions in Italy which are not part of the RCT. Instead, in this study, all participants are considered.

Furthermore, this paper focuses on the teachers' confidence in spatial thinking. As emphasised in the context, the role of teachers is crucial in increasing attraction towards STEM careers and addressing gender bias. Mainly, reinforcing spatial ability is essential for ensuring proper pupil development. Therefore, it is pertinent to investigate primary school teachers' baseline spatial thinking levels and their teaching backgrounds' impact as a crucial first step to reach an impact on the students.

The primary research questions are (i) To what extent are primary school teachers aware of gender bias? (ii) What can be said about the level of spatial ability among primary school teachers?

4 Methodology

4.1 Theoretical framework

The Matabì project uses playful-educational activities with bricks to improve math learning, reduce anxiety, and address gender biases in education [21]. Construction play fosters engagement, creativity, and deep learning through hands-on experiences [23]. By incorporating this approach, the project aims to enhance students' mathematical understanding and spatial thinking [24]. Playful learning can also reduce anxiety and increase motivation [21]. The project draws on research highlighting the benefits of construction play in math education.

4.2 Sample

The sample for this study comprised teachers who taught classes in the third and fourth year of primary school and participated in the Matabì project during two distinct phases: a pilot phase from October 2022 to January 2023 in Turin and a national edition from February 2023 to May 2023 across multiple regions in Italy.

During the pilot phase, 15 teachers and their respective 16 classes (about 340 students) were involved, with the activities taking place in five schools in Turin. Feedback was collected during this phase to gather insights and inform enhancements for future project iterations.

In the national edition, a larger sample of 69 teachers and their 72 classes (about 1430 students) participated, selected from 17 schools in Piedmont, Tuscany, Campania, and Veneto.

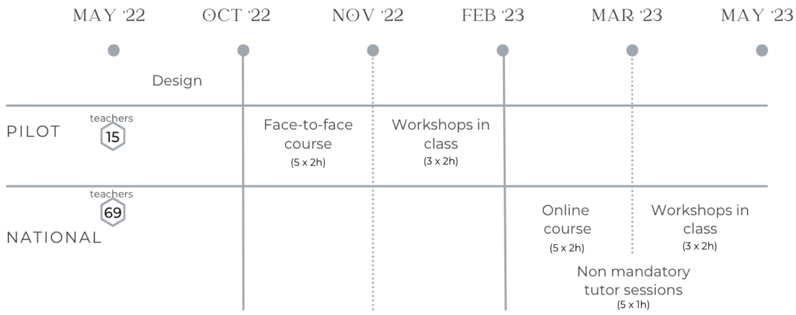
The sample size notably increased from the pilot phase to the national edition, indicating a more extensive reach and implementation of the Matabì project. Including multiple schools and regions further suggest a broader representation and potential generalizability of the study's findings. Incorporating schools from diverse urban (11) and rural (6) contexts in different Regions provides a varied backdrop for examining the project's impact. Teachers had an average age of 48.65 years, with some individuals younger than 30 and others older than 60.

Overall, the sample composition comprehensively represents teachers and their classes, enabling a robust analysis of the Matabì project's effects on spatial thinking and gender bias in mathematics education.

4.3 Design

We provide a description of the design and the methods employed for data collection, focusing on the two training modalities: face-to-face and online (Fig. 1).

Fig. 1. Matabì design implementation timeline



Matabì prioritises working directly with teachers to ensure the project's long-term sustainability. Training teachers allow the methodology to be effectively disseminated and consistently applied even when they have new classes. The teacher training program, conducted both in face-to-face and online formats, aims to equip educators with the necessary knowledge and skills to implement the Matabì project effectively. The face-to-face training involves in-person sessions, while the online training is conducted remotely using virtual platforms. The 10-hour training covers essential components, including theoretical foundations, instructional strategies, and integrating the Matabì kit into the classroom environment. Both training modalities cover the same content and duration, ensuring consistency in the knowledge and competencies acquired by the participating teachers. All recorded materials are made available to the teachers.

The training program consists of five modules that address various topics, such as the impact of gender stereotypes on mathematics learning gaps, the significance of spatial skills in mathematical understanding, an introduction to the Matabì kit, and associated teaching methodologies. Through these modules, teachers gain insights into effective instructional practices and acquire the necessary tools to design engaging class activities using Matabì bricks. Notably, the second meeting and the first part of the third meeting focus on personal training on spatial ability. Trainers utilise three modules from the Sorby course [25] to provide hands-on training in spatial thinking, including coded plan, isometric drawing, and rotation around one axis.

The first pilot employed face-to-face training sessions that emphasise direct interaction, enabling immediate feedback and promoting a dynamic exchange of ideas.

The second edition transitioned to an online format, offering flexibility and accessibility for teachers in different locations. Teachers accessed instructional materials, video lectures, and interactive live sessions through an online platform. The online training modules were partially self-paced, allowing teachers to receive support and feedback through emails and virtual tutoring meetings, ensuring ongoing engagement and clarification of concepts.

A primary difference between the first and second editions was the “spatial gym” component. In the first pilot edition, more time was allocated for in-class exercise solving (approximately 3 hours), while the online edition dedicated less than two hours to personal training, making the remaining material available through recorded videos. Although five non-mandatory tutoring sessions were organised to support training, address doubts, and discuss different strategy solutions.

Post-training, three workshops with trained tutors supported Matabì integration in classrooms. Workshop 1 focused on geometry introducing angles (third year) and triangles (fourth year). Tutor-led, it boosted teachers' confidence in using Matabì for geometric concepts. Workshop 2 let teachers lead, concentrating on measurements such as lengths (third year), areas (fourth year), and equivalences. The Matabì kit served as a powerful tool for facilitating students’ comprehension of these mathematical principles. Workshop 3, teacher-led, explored spatial mathematics with isometries, including symmetry and translations (third year) and rotations (fourth year) with hands-on brick activities. These in-class activities and workshops were complemented by the creation and execution of an additional workshop, allowing each teacher to design personalised learning experiences for their students.

4.4 Data Collection and Instruments

Multiple sources were utilised to gather comprehensive data on the teachers’ experiences and outcomes. Firstly, pre and post-training surveys were administered to assess teachers’ baseline spatial ability levels and their awareness of gender bias in daily teaching practices. These surveys included validated instruments such as the 30-items Revised Purdue Spatial Visualization Test: Visualization of Rotation (Revised PSVT:R) [26] and the Gender-Science Implicit Association Test (IAT) [27]. The surveys captured quantitative data that could be analysed to identify changes in spatial ability and awareness of gender bias.

In the first pilot edition, the Revised PSVT:R was administered in a paper and pencil format, while in the second edition, it was conducted online with supervision. The IAT was included in the RCT baseline test for the 44 teachers in Turin. The test was administered on a computer, and a facilitator was present to provide support and record the results. It should be noted that the IAT was not administered as part of the post-training assessment.

5 Findings and discussion

To address the first research question, we analysed the IAT results. The test assess participants' implicit gender-science associations by focusing on the magnitude of bias rather than the direction of bias. The results (Table 1) indicate that out of the total 44 participants, 22.73% exhibited a strong association, 34.09% displayed a moderate bias, 11.36% showed a slight one, and 31.82% demonstrated no discrimination in their gender-science associations.

Table 1. Distribution of the results of the Implicit Association Test.

Association	Number	Percentage
Strong	10	22.73
Moderate	15	34.09
Slight	5	11.36
No	14	31.82
Total	44	100

These findings are consistent with 846,020 IAT scores for the Gender-Career task completed between 2003 and 2015, which reported similar proportions of strong and moderate associations [28]. The prevalence of strong and moderate biases observed in our study suggests the persistence of implicit gender-science associations, indicating the presence of societal stereotypes and cultural influences on individuals' perceptions.

Notably, nearly one-third of the study participants showed no bias in their gender-science associations. This encouraging finding suggests the potential for neutral or unbiased attitudes towards gender and science. Further exploring the factors contributing to this lack of bias may offer insights into effective strategies for promoting gender equality in science education.

Our study contributes to understanding implicit biases in the context of gender and science, supporting the notion that biases exist but are not universally held. These findings underscore the efforts needed to address and mitigate biases, impacting attitudes and decision-making.

It is important to acknowledge the limitations of the present study, including the relatively small sample size and the specific context in which it was conducted. Future research needs larger, diverse samples for a comprehensive understanding of implicit biases in mathematical education. Additionally, qualitative data and interviews would offer valuable insights on gender-science associations.

Moving on to assessing the Matabì project's impact on teachers' spatial ability, our findings demonstrate significant improvements among the participants despite their non-voluntary involvement in the training program. The baseline assessment using the Revised PSVT:R involved 76 teachers, who achieved an average score of 10.09 (SD=6.18), aligning with existing literature that locates the education community as the poorest one on spatial ability [6].

The end-line assessment included 52 teachers, with an increased average score of 12.94 (SD=5.88). Notably, 47 teachers completed both the pre and post-tests, enabling a direct comparison of their performance. The two-sample t-test with equal variances revealed a significant improvement in spatial ability, with a mean increase of 2.57 ($t(92)=2.14$, $p=0.035$) in the number of correct answers in the post-test, corresponding to 25% increase in the score.

The observed improvement in spatial ability highlights the effectiveness of the Matabì project's interventions and training programs in enhancing teachers' spatial thinking skills. This indicates the project's potential to positively impact teachers' professional development and subsequently improve students' learning outcomes.

Moreover, our sample composition, which includes teachers who may not have been initially motivated to participate, strengthens the generalisability of the findings, providing a realistic portrayal of the broader teaching community. Additionally, comparing the baseline results with existing literature on spatial ability in STEM domains further reinforces the significance of spatial thinking skills in mathematics education.

Furthermore, examining two pilot editions, one conducted face-to-face with deeper spatial learning and the other conducted online, revealed noteworthy differences. The face-to-face pilot exhibited a baseline mean of 9.08 and a post-test mean of 13.02, while the online pilot showed a baseline mean of 10.28 and a post-test mean of 12.88. Although the analysis is limited due to the difference in the number of teachers between the editions, it is evident that face-to-face training yielded better results. This advantage can be attributed to the facilitation of physical presence, which fosters collaboration, interaction, and longer-duration engagement for personal improvement.

The present study focused solely on teachers' spatial ability and did not explore other potential outcomes or factors that may influence the effectiveness of the Matabì project. Future research should aim for a more comprehensive understanding of the impact.

Overall, our findings suggest that the Matabì project effectively enhances teachers' spatial ability, contributing to their professional development and potentially benefiting students' learning outcomes. These positive results underscore the potential of incorporating playful learning and LEGO-based activities in mathematics education to foster spatial thinking and promote a deeper understanding of geometric and spatial concepts.

6 Conclusions

This study aimed to address the research questions regarding primary school teachers' awareness of gender bias, the level of spatial ability among these teachers, and strategies to enhance understanding and improve the existing situation.

The findings shed light on the extent of gender bias in daily teaching practices. A significant proportion of participants exhibited implicit biases in their gender-science associations, with a notable prevalence of strong and moderate tendencies. However, it is encouraging that approximately one-third of the participants displayed no bias, indicating the potential for more equitable attitudes. These results underscore the ongoing need for interventions and educational initiatives to mitigate implicit biases and promote gender equality in mathematics education.

Regarding the level of spatial ability among primary school teachers, the study reveals a general weakness in mental rotation ability, consistent with existing literature. This suggests that the current educational programs may not sufficiently reinforce personal spatial thinking skills, thereby affecting the indirect teaching of spatial ability. However, the Matabì project demonstrates its statistical significance in positively impacting teachers' spatial ability, even among those who initially lacked interest in the program. The project's interventions and instructional strategies effectively enhance teachers' spatial thinking skills, offering a promising approach to improving STEM education. Including non-self-selected teachers in the sample enhances the external validity of the findings, providing valuable insights into the broader teaching community. Future research should investigate the long-term sustainability of the observed improvements and explore the specific mechanisms underlying the effectiveness of face-to-face training in enhancing spatial thinking skills.

In conclusion, this study contributes to the existing body of knowledge by highlighting the importance of addressing gender bias and enhancing spatial ability among primary school teachers. The results emphasise the need for continuous efforts to promote gender equality and spatial thinking in mathematics education. By implementing evidence-based interventions such as the Matabì project, educators can cultivate more equitable attitudes and improve spatial thinking skills, ultimately benefiting both teachers and students. The positive initial impressions of Matabì's impact on math learning are expected to pave the way for its expansion to schools nationwide. These findings provide a foundation for further research and inform the development of comprehensive strategies to enhance STEM education and foster inclusive learning environments.

Acknowledgement

The authors gratefully acknowledge the financial and management support from Exor and Fondazione Giovanni Agnelli, as well as the valuable contributions from The LEGO Foundation. Special thanks are extended to the teachers and students who participated in the project, whose collaboration was essential for the success of this research.

References

1. OECD: The ABC of gender equality in education (PISA). OECD Publishing (2015).
2. OECD: PISA 2018 Results (Volume II): Where All Students Can Succeed (PISA) OECD Publishing (2019).
3. Currie, J. & Almond, D.: Human capital development before age five. Handbook of Labor economics, 4: 1315–1486 (2011).
4. Çetin, M. , Demircan, H. Ö. , Şenyurt, E. , Ata Aktürk, A.: An Analysis of Young Children's Preferences on STEM Activities in terms of Gender. Journal of Education and Future 18: 1-15 (2020).
5. Lowrie, T. & Jorgensen, R.: Gender differences in students' mathematics game playing. Computers & Education 57(4): 2244-2248 (2011).
6. Wai, J., Lubinski, D., & Benbow, C. P.: Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. Journal of Educational Psychology 101(4): 817–835 (2009).

7. Moè, A., Meneghetti, C., & Cadinu, M.: Women and mental rotation: Incremental theory and spatial strategy use enhance performance. Personality and Individual Differences 46(2):187–191 (2009).
8. INVALSI: Microdati Campione G02 2021-22 [Dataset] processed by Fondazione Agnelli (2022a).
9. INVALSI: Microdati Campione G05 2021-22 [Dataset] processed by Fondazione Agnelli (2022b).
10. Eliot, L.: Pink brain, blue brain: How small differences grow into troublesome gaps and what we can do about it. Mariner Books (2019).
11. Fine, C.: Delusions of gender: How our minds, society, and neurosexism create difference. W. W. Norton & Company (2010).
12. Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S.: The malleability of spatial skills: A meta-analysis of training studies. Psychological Bulletin 139(2): 352–402 (2013).
13. Casey, B. M., Andrews, N., Schindler, H., Kersh, J. E., Samper, A., & Copley, J.: The development of spatial skills through interventions involving block building activities. Cognition and Instruction 26(3): 269–309 (2008).
14. Will, J. A., Self, P. A., & Datan, N.: Maternal behavior and perceived sex of infant. American Journal of Orthopsychiatry 46(1): 135–139 (1976).
15. Carlana, M.: Implicit stereotypes: Evidence from teachers' gender bias. Journal of Political Economy 127(5): 2343–2388 (2019).
16. Belotti, E. G.: Dalla parte delle bambine. L'influenza dei condizionamenti sociali nella formazione del ruolo femminile nei primi anni di vita. Feltrinelli (1973).
17. Biemmi, I.: Educazione sessista. Stereotipi di genere nei libri delle elementari. Rosenberg & Sellier, Torino (2017).
18. Spencer, S. J., Steele, C. M., & Quinn, D. M.: Stereotype threat and women's math performance. Journal of Experimental Social Psychology 35(1): 4–28 (1999).
19. Betz, N. E., & Hackett, G.: The relationship of mathematics self-efficacy expectations to the selection of science-based college majors. Journal of Vocational Behavior 23(3): 329–345 (1983).
20. Di Liberto, A.: Spatial abilities and gender gap in mathematics (Matabì). AEA RCT Registry. February 07, https://doi.org/10.1257/rct.10914-1.0 (2023).
21. The LEGO Foundation: Learning through play: a review of the evidence. White paper. ISBN: 978-87-999589-1-7 (2017).
22. Richardson, M., Jones, G., Croker, S., & Brown, S.: Identifying the task characteristics that predict children's construction task performance. Appl. Cognit. Psychol. 25: 377–385 (2011).
23. The LEGO Foundation: Neuroscience and learning through play: a review of the evidence. White paper. ISBN: 978-87-999589-2-4 (2017).
24. Piaget, J.: Play, dreams, and imitation in childhood. Norton (1962).
25. Sorby, S.: Assessment of a "New and Improved" Course for the Development of 3-D Spatial Skills. Engineering Design Graphics Journal 69(3): 6–13 (2005).
26. Yoon, S. Y.: Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R) [Psychometric Instrument].
27. Greenwald, A. G., McGhee, D. E., & Schwartz, J. L.: Measuring individual differences in implicit cognition: the Implicit Association Test. Journal of Personality and Social Psychology 74(6): 1464 (1998).
28. Xu, K., Nosek, B.A., Greenwald, A.G., Ratliff, K.A., Bar-Anan, Y., Umansky, E., Banaji, M.R., Lofaro, N., Smith, C., Axt, J., Lai, C.K., Simon, L., O'Shea, B., Frost, N.: Project Implicit Demo Website Datasets. OSF (2023).