



# Why Spatial Reasoning Matters for Education Policy

By Jonathan Wai and David H. Uttal

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## Key Points

- Most tests and school curricula are primarily suited to the types of students who excel in mathematics and verbal reasoning.
- The missing factor in testing and education policy is the measurement, selection, and talent development of students with strengths in spatial reasoning—the ability to generate, retain, retrieve, and transform visual images.
- The failure to identify spatial reasoning capacity throughout K–12 and higher education leads society to neglect many potential innovators and even “future Einsteins and Edisons” from disadvantaged backgrounds.
- Including spatial measures in tests, teaching spatial reasoning, educating teachers, and developing matching curriculum to help students with spatial reasoning strengths are policy solutions that could significantly expand educational opportunities and improve innovation in society.

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*“At the present time, there is a developing educational crisis, because of the unsatisfied demand for personnel trained and qualified in all fields in which spatial ability is of fundamental importance. The technical revolution has put a premium on spatial ability at all levels, whether required for tile-laying or for topology.”<sup>1</sup>*

—I. M. Smith, 1964

In schools today, tests and curricula are primarily suited to the types of students who excel in mathematics and verbal reasoning. The missing factor in testing and education policy is the measurement, selection, and talent development of students with strengths in spatial reasoning. Spatial reasoning is linked to positive educational outcomes in STEM and is a strong predictor of success in the visual arts and vocational, manufacturing, and technical careers.

Students with this ability are not being identified or developed effectively. Consequently, society is missing out on innovation from a larger pool of spatially talented individuals who could be engineers

and inventors if their abilities were more fully developed. Including spatial measures in tests, teaching spatial reasoning, educating teachers, and developing matching curriculum are policy solutions that could significantly expand opportunities for students with spatial reasoning strengths, while simultaneously improving innovation in society.

## What Is Spatial Reasoning?

Spatial reasoning can be defined as “the ability to generate, retain, retrieve, and transform well-structured

visual images.”<sup>2</sup> It is related to the shape, size, orientation, location, direction, or trajectory of objects and their relative positions.

Spatial reasoning uses the properties of space as a vehicle for structuring problems, finding answers, and expressing solutions.<sup>3</sup> For example, an individual with strong spatial reasoning skills might easily construct mental models of objects from verbal descriptions or visualize how parts of a machine interact with each other. Spatial skill or reasoning can be measured through reliable and valid paper-and-pencil tests, which assess the ability to mentally rotate and visualize objects in three dimensions.<sup>4</sup>

## What Is the History of Spatial Reasoning?

Spatial ability has played a significant role in major thinkers’ and inventors’ lives. According to I. M. Smith, the lintel above the entrance to Plato’s Academy bore the inscription “Let no one ignorant of geometry enter my door,” and knowledge of geometry was used as a screening device for admission to the school.<sup>5</sup> This shows historical emphasis on geometry, a subject that relies heavily on spatial reasoning.

Nikola Tesla, who created the basis of alternating current power systems, had a remarkable talent for envisioning his inventions in his mind’s eye before building them. When out walking, the idea for a “brushless AC motor” came to him, and he sketched its “rotating electromagnets” in the sand.<sup>6</sup> Supposedly, he could envision an entire working engine in his mind and visually test each part of the engine to determine which component might be the first to fail.

Albert Einstein famously imagined chasing after a light beam. This *gedankenexperiment* led to his first published paper, at age 16, titled “The Investigation of the State of Aether in Magnetic Fields,” and eventually to the creation of the theory of relativity.<sup>7</sup>

Spatial reasoning has a rich history among academic scholars as well. Some of the first experimental research into spatial ability and mental imagery came from Sir Francis Galton starting in 1880.<sup>8</sup> However, the role of spatial ability and its importance in education would not be seriously studied until the early 1960s, most notably by I. M. Smith and later by D. F. Lohman and D. Lubinski.<sup>9</sup> Since then, a resurgence

of research on spatial ability and its connection to education has occurred.<sup>10</sup>

## Why Is Spatial Reasoning Important?

Many studies have documented the importance of math and verbal reasoning in predicting success in educational and occupational domains, including the humanities and STEM.<sup>11</sup> But another body of work has found spatial reasoning to be a strong predictor of success over and above math and verbal reasoning in educational and occupational domains.<sup>12</sup>

Spatial reasoning is key to innovation in STEM fields, which have been of particular interest in societal and scientific innovation.<sup>13</sup> Research suggests spatial reasoning may be more important for STEM degrees than for other degrees, and by extension likely important for vocational degrees and professions that require the ability to imagine in the mind’s eye. Unsurprisingly, students with higher spatial ability tend to gravitate toward STEM and vocational fields, such as engineering and manufacturing professions.

Creativity today is associated often with acting, dancing, artistry, music, and writing. One often hears about the incredible creativity of the latest pop song but rarely about the highly pragmatic creativity of an engineer or the imaginative creativity of a mathematician. Meanwhile, longitudinal research has linked early spatial talent and later creativity.<sup>14</sup> While society may understand the economic value of STEM, it often overlooks STEM’s creative value, at least in public discourse.

To argue that alternating current, the theory of relativity, and the light bulb are not creative inventions is simply incorrect. These are all STEM innovations, made possible in part by spatial thinking. Even the device you may be using to read this report was envisioned in the mind’s eye of many inventors, from the computer engineer to the designer.

Besides the STEM fields, spatial skills may also play a particularly important role in vocational and other middle-skill jobs. For example, Katherine Newman and Hella Winston lamented the lack of qualified middle-skill talent today.

Employers complain that electricians, pipe fitters, advanced manufacturing machinists, brick masons and radiology technicians are

scarce. More than 600,000 jobs remain open in the manufacturing sector alone. These are jobs that provide a middle-class wage without a traditional four-year college degree.<sup>15</sup>

Individuals with high spatial skills are good candidates to fill these jobs, as the jobs often require spatial reasoning. However, because spatial skills are rarely identified and developed and because educational and career counseling may inadequately match skills to education and later careers, many of these individuals may underachieve and fall through the cracks.<sup>16</sup>

Consider the continuum of spatial talent. At the top are the talented people employed by organizations such as Elon Musk’s SpaceX, those who have been bending metal and building things since they were little. But those are not the only spatial jobs available; there are many middle-skill jobs that spatially talented kids could also help fill. And yet, largely because the majority of educational selection tests from K–12 do not include spatial measures and because schools focus on verbal and mathematical skills, many of these spatially talented kids fail to be identified and consequently are prone to underachievement.<sup>17</sup>

If talent is not identified early on, it is hard to develop it properly. Kids with high spatial reasoning who may have the talent and inclination to fill many of these middle-skill jobs are not being encouraged to do so. This is because schools focus almost exclusively on math and verbal reasoning and do not pay enough attention to the skills associated with vocational and other middle-skill jobs.

Of course, not all students will become Einsteins or Edisons. But there is a large pool of neglected and underserved students whose talents go unrecognized in the current system. Their ability to visually imagine and build could help create future innovations, and their talent should be fully developed.

### **What Is Missing in Standardized Tests? How Does This Affect Higher Education?**

Although noted scholars provided evidence for including spatial reasoning in identification and educational practice, uniformly assessing spatial talent is absent in education.<sup>18</sup> Perhaps this is because spatial reasoning has been typically linked to vocational and trade professions, which have fallen out of favor

in an educational system focused primarily on preparing students for college.

Standardized tests usually include math and verbal reasoning, but not spatial reasoning. Given the importance of spatial skills, their lack of inclusion on standardized tests creates a weakness for educational policy and practice. Missing spatial measures can have implications for identifying and nurturing talent.

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There is a large pool of neglected and underserved students whose talents go unrecognized in the current system.

For example, almost 100 years ago, Lewis Terman used the highly verbal Stanford-Binet intelligence test—a test initially designed to measure cognitive abilities in developmentally challenged children—as part of a “search” for talent across California. William Shockley and Luis Alvarez, who would go on to become famous physicists and win the Nobel Prize for work in areas that depended on high levels of spatial reasoning, were not identified. One explanation is that many items on the Stanford-Binet test failed to measure spatial reasoning ability.<sup>19</sup> Although this example is at the high end of achievement, this concept translates throughout the distribution of spatial talent, from scientific prize winners and Tesla engineers to machinists and those in many vocational trades.<sup>20</sup>

Because college admissions tests such as the SAT, ACT, and GRE do not include spatial reasoning measures, students who have spatial reasoning strengths but relative math and verbal reasoning weaknesses are likely disadvantaged in the college and graduate school admissions process, despite many colleges’ and graduate programs’ need of students with such strengths. This produces a bias toward students with sufficiently high math and verbal abilities, which is a core problem throughout higher education.

The lack of spatial measures in high-stakes testing likely has had a cumulative effect over decades. Many potential innovators, engineers, and professionals who work with their hands and imagine with their

mind's eyes simply have not had the chance to fully develop and demonstrate their capacities.

## Can Spatial Reasoning Be Trained and Tested?

As spatial reasoning has typically been undervalued in school systems (e.g., such measures are largely absent from standardized tests), such reasoning capacities may not have been developed to the fullest extent they could be, especially for certain disadvantaged populations that may lack opportunities.<sup>21</sup>

Scholars have begun to develop ways to train spatial reasoning. Some of the most effective spatial training interventions focus on tasks that center on drawing and three-dimensional rotation and thinking—the types of experiences one might encounter in an engineering curriculum.<sup>22</sup> Early spatial reasoning training studies have demonstrated a positive effect.<sup>23</sup>

More broadly, a major meta-analysis has shown that different methods of spatial reasoning training appear to have positive effects.<sup>24</sup> These researchers analyzed more than 200 studies, ranging from formal instruction on tasks such as mental rotation to less formal activities such as playing spatially demanding video games. They found that spatial skills consistently improved with training and experience. Spatial reasoning training appears to be one important approach to helping improve the basic capacities that predict performance in STEM and other vocational areas.

Even today, some tests, such as the Dental Admissions Test (DAT), do include spatial reasoning measures because such skills are crucial for performance during training and in dental practice. However, though such spatial reasoning measures have been developed and could be incorporated, the largest consideration and challenge from the testing company's perspective is that spatial reasoning measures tend to show large gender differences favoring males.<sup>25</sup>

## Who Would Be Helped Most by Enhanced Testing and Educational Development?

Gender differences in favor of males have been documented in spatial reasoning. These differences appear at a young age and persist throughout educational development.<sup>26</sup>

Also, students who excel in spatial reasoning tend to come from relatively lower-income backgrounds. Meanwhile, nationally representative samples of the US population indicate that students who have higher scores on math and verbal reasoning measures tend to come from relatively higher-income backgrounds.<sup>27</sup> One possible explanation is that US families with higher incomes provide their children with more enrichment in subjects that are tested, such as math and reading.

Broadly speaking, however, most spatially talented students are under-identified. The school system does not provide enough challenges for these students. This likely leads to reduced educational development from K–12 to higher education and reduced innovation for society.

## Core Recommendations for Innovations and Reforms in Education Policy

Spatial reasoning needs to be systematically identified and trained, and educational programming should be provided to enhance students' talent development. These overarching themes could also readily apply to a company's talent acquisition mechanisms, but our focus here is on the educational pipeline. The point of hiring may be too late for many students who were not identified and could not develop their talents earlier.

Below we have highlighted potential reforms that would better develop spatial talent.

**Earlier Spatial Reasoning Identification, Training, and Educational Development.** Our core policy recommendations of identification, training, and educational development need to be implemented as early as possible in K–12 education. Research has shown that early investments in educational development lead to large payoffs in the long run. However, without identifying students with spatial strengths, it is unclear at what level educational development suited to those strengths should be provided.<sup>28</sup>

Spatial training, especially in terms of introducing spatial thinking and reasoning to students, might be implemented broadly in some capacity in the K–12 curriculum.<sup>29</sup> Additionally, other programs that encourage and develop spatial strengths, such as the maker movement and robotics competitions, might

be leveraged to help all students build their spatial reasoning capacity.

**Teacher Training and Familiarity Regarding Spatial Reasoning.** Teacher training should include an understanding of the research on spatial reasoning. The training might include reviewing the research on:

- The importance of spatial reasoning for many long-term educational and occupational outcomes,
- The role that spatial familiarity and training might play in improving spatial reasoning among students,
- How tests should include spatial measures to identify students with such strengths, and
- How curricula may be adapted for learners with spatial strengths who like working with their hands or visualizing with their mind's eyes.

**Identifying a Broader Base of Low-Income Talent.** Research has indicated that encouraging all students to take the SAT or ACT might increase opportunities.<sup>30</sup> In addition, including spatial measures in the SAT and ACT exams would help identify a broader base of low-income talent.<sup>31</sup>

Colleges and universities today already have departments—such as engineering and other STEM areas—for students with spatial strengths. However, the students who have made it into and are thriving in engineering and other STEM departments also had to have reasonable strengths in math and verbal. This is because the two major college entrance examinations—the SAT and ACT—focus primarily on math and verbal reasoning and lack a spatial measure.

So some individuals are left outside higher education's gates because their strengths are primarily spatial rather than mathematical or verbal. In a stratified random sample of America's high school population—from the study Project Talent—a large fraction of the most spatially talented thinkers had relatively lower mathematical and verbal scores.<sup>32</sup> These students—not limited to the most talented but throughout the continuum—would be well served by college curricula that focus on spatial strengths or by vocational schools that require spatial reasoning and the ability to work with one's hands.

Colleges and universities do not necessarily undervalue spatial talents once the students arrive on campus. For example, excellent science and engineering departments recognize the role spatial skills play in their fields. But many spatially talented students who are not as good with words or numbers have simply not made it there. And this is because their K–12 education has not been tailored to the way they think.

**Spatial Reasoning Incorporated into Personalized Learning.** Computer-based instruction and learning will likely increase personalization of learning due to intelligent systems and the skills likely required for jobs in an artificial intelligence–filled future. For example, in a report titled “Artificial Intelligence and Life in 2030,” researchers at Stanford University wrote:

While formal education will not disappear, the Study Panel believes that MOOCs and other forms of online education will become part of learning at all levels, from K–12 through university, in a blended classroom experience. This development will facilitate more customizable approaches to learning, in which students can learn at their own pace using educational techniques that work best for them. Online education systems will learn as the students learn, supporting rapid advances in our understanding of the learning process. Learning analytics, in turn, will accelerate the development of tools for personalized education.<sup>33</sup>

These future personalized learning systems should account for spatial reasoning, training, and educational development.

**Innovation in Curriculum and Program Development for Spatial Talent.** Curriculum in many areas throughout K–12 and higher education should be adapted to account for students with spatial strengths.<sup>34</sup> For instance, many programs in vocational areas or trades could be adapted to accommodate students with spatial and mechanical strengths and interests. This tailored curricula might include hands-on experience, the use of virtual reality in

learning, or other ways of teaching that would connect with students with spatial strengths.

## What Are Some Potential Barriers to Reform?

One important issue with including spatial reasoning measures in standardized tests is that such measures show large gender differences favoring males, even starting from infancy.<sup>35</sup> Companies that develop standardized tests likely do not wish to include measures that could reduce the inclusion of females.

Although this may seem to be a core concern, it actually provides even more reason, in our view, to ensure that females are made familiar with spatial reasoning early in the K–12 curriculum. If the goal is to aid spatially talented females and low-income students, including spatial measures will do much more to help these students than to disadvantage specific subgroups.

Additionally, educators throughout K–12 and higher education tend to have lower spatial and higher verbal and math skills. Thus, they may be less likely to

readily identify spatial talent among their students, who are different from them.<sup>36</sup>

## Conclusion

Our recommendations are simple: Spatial reasoning should be accounted for throughout K–12 and higher education, with a focus on identifying students with spatial strengths, including spatial reasoning in the curriculum, and developing differentiated curricula that suit the needs of spatial learners throughout the educational spectrum.

Implementing these simple policy changes would help identify and develop talented but disadvantaged students; narrow opportunity, achievement, and excellence gaps; and improve the talent pipeline for vocational, middle-skill, and STEM jobs. These changes would also improve innovation in many sectors of society. Most importantly, recognizing spatial reasoning as a missing core factor in education policy would help students with such strengths flourish and develop to their full capacity.

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