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Art & Science: Visual arts training improves visuo-spatial ability and mediates STEM success

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Abstract

Effects of visual arts training on the visuo-spatial ability of students can inform educational practices that aim to incorporate the visual arts into STEM education. Studies have shown visuo-spatial ability and spatial reasoning to be a critical cognitive domain for scientific thinking and a strong predictor of STEM success. Recent findings show that visual arts practice and training correlates with and could improve visuo-spatial ability. Drawing practice has been identified to be a mediating factor for that connection. Studies that inform the psychological mechanisms underlying this phenomenon are discussed and future research avenues are identified based on the challenges faced by current research. The potential advantages of having visual arts training complement STEM education, a practice that has become popular in the US during the last two decades, are highlighted to complement current educational research on the matter.

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Background: Visuo-spatial Ability

Visual arts training can result in improvements in many ability domains. It comes as no surprise that someone who has received training in the visual arts or someone who practices visual arts can draw better than a non-artist for example. However, the difference in one cognitive domain is especially salient for the contemporary discussion of the effects of visual arts training and practice on one's mental faculties: spatial reasoning, a cognitive domain that has been linked numerous times to scientific achievement (Ganley et al., 2014, p. 1420). As a measurable manifestation of spatial reasoning, individuals' performance on tasks that measure visuo-spatial ability has been at the center of many studies, thus, visuo-spatial ability has been the most consistently quantified assessment of an individual's spatial reasoning (Kozbelt, 2001; Snow, 1999; Kozhevnikov et al., 2007; Stavridou & Kakana, 2008; Chamberlain et al., 2019).

Visuo-spatial ability has been often and consistently measured by some form of the "Mental Rotation" task, first described by Shephard & Metzler half a century ago (Shepard & Metzler, 1971). The task gives subjects two-dimensional drawings of three-dimensional objects, usually comprised of uniform cubic subunits, from various perspectives and asks them to match the two-dimensional drawings in a given array that belong to the same three-dimensional object. This requires the subjects to create mental images of the objects in their mind's eye, manipulate them and map them onto two-dimensional images of others (Ganley et al., 2014, p. 1421). These skills are collectively taken to be representative of an individual's visuo-spatial ability, and have been utilized by the field over many decades (Chamberlain et al., 2019; Ganley et al., 2014; Kaufman, 2007; Kozbelt, 2001; Kozhevnikov et al., 2007; Snow, 1999; Stavridou & Kakana, 2008).

Visuo-spatial ability has been found to be critical for scientific thinking and predictive of individuals' success in STEM-based tests (Ganley et al., 2014; Kaufman, 2007). The recent evidence from Ganley et al. suggests that individual differences in visuo-spatial ability could be the major underlying factor for the gender-gap and underrepresentation of women in STEM fields, a pressing issue that contemporary educational approaches are trying to alleviate. Previous research had shown a male advantage in spatial ability and science achievement, which prompted Ganley et al. to test the potential role of spatial skills in gender differences in the science performance of 13–15-year-old students.

In their first study, the effect of spatial skills (which correlates with gender) on scientific aptitude was evaluated to understand whether the former mediates the latter. The experimenters hypothesized that gender alone would be a poorer predictor of science test scores once spatial ability was included as a co-predictor in the predictive model. The spatial ability of eight grade students (N=113) was assessed by the mental rotation test, then the results of the same set of students in a separate science aptitude test were correlated with their gender and spatial ability. Mediation analyses showed that gender was found to be less predictive of students' success when spatial ability was introduced as a co-factor in a regression model. This evidence suggests that gender differences in scientific aptitude are to some extent mediated by spatial ability.

A separation analysis showed that spatial ability was a better predictor of physical science and engineering domains of scientific reasoning; students' success in questions from the biological sciences weren't mediated by spatial ability or gender (Ganley et al., 2014, p. 1424). Their second study corroborated this finding: science performance was examined in a state population of eighth-grade students (N = 73,245). As in the first study, the results revealed larger gender differences on questions that showed higher correlations with mental rotation (more in the physical and engineering science domain rather than the biological sciences domain). These findings are especially interesting, considering that women are represented more in the biological sciences compared to physical sciences, math and engineering (Wang & Degol, 2017, p. 120). Together, these findings suggest that spatial ability could be a mediating factor for gender differences in scientific domains that rely heavily on spatial reasoning.

Ganley et al. proposed an explanation for this difference by assuming that “knowledge in the area of technology/engineering may be acquired [by boys] in noncurricular ways, such as working with cars and machines or participating in technology-related clubs” (Ganley et al., 2014, p. 1429). While culturally restricted anecdotal evidence might support the presumption of a developmental male advantage due to their *experience with cars*, “research on sex differences has done remarkably little to elucidate the nature of the differences between various kinds of tests [of spatial ability] or the differences in the psychological operations they engage” (Kaufman, 2007, p. 212). Kaufman highlights the need for empirical studies, that do not rely on presumed socio-cultural norms, to elucidate the mechanism for the gender difference in spatial ability.

Kaufman hypothesized that working memory capacity could mediate this spatial ability differential in males and females (Kaufman, 2007). He tested 16-18-year-old students (m=50, f=50), who took tests of three-dimensional mental rotation and spatial visualization, along with tests of spatial and verbal working memory. The mediation analysis conducted to statistically investigate the test results show that both verbal and spatial memory correlate with spatial ability, but only spatial working memory completely mediates the relationship between sex and spatial ability (Kaufman, 2007, p. 217). That indicates that working memory is an important cognitive factor that underlies spatial ability, which in turns has been found to predict STEM success.

Numerous findings support the notion that spatial ability is *malleable* and *improvable*, as University of Chicago professor Susan Levine argues in her lectures (S. Levine, 2020). These findings underscore the importance of considering spatial training interventions aimed at reducing gender differences in the science performance of school-aged children (Ganley et al., 2014, p. 1419). That raises the question: what kind of training could be used to improve spatial ability? Kaufman’s investigations of the cognitive roots of this phenomenon forms the basis of mechanistic discussions of potential visual-arts based training interventions. This literature review will present recent work in the field that show visual art training having a positive impact on individuals’ spatial skills on various time scales. These studies suggest that the spatial training intervention required to alleviate the gender gap in STEM could come in the form of visual arts training. The psychological research in the cognitive benefits of visual arts training can inform educational research to its value in supplementing scientific education and prompt future research to evaluate the success of such pedagogic practices.

Effects of Visual Arts Training on Visuo-spatial Ability

Seminal work that paved way for future research about the cognitive effects of visual arts training was done by Kozbelt, who addressed the question of how artists differ from non-artists in visual cognition (Chamberlain et al., 2019; Kozbelt, 2001). To assess the effects of arts training and practice on visuo-spatial ability and drawing skill, he compared 17 first-year art students (m=5, f=12), 13 fourth-year art students (m=4, f=9), and 16 novices (m=11, f=5) on a mental rotation task, three perception tasks and twelve drawing tasks. Artists unsurprisingly outperformed non-artists on all drawing tasks, perceptual tasks and the mental rotation task. This difference may seem like it is originating from the already better visuo-spatial ability of individuals that have chosen to undergo art training vs those that have not, considering that no significant improvement is seen for 1st and 4th year students. However, Kozbelt posits that the 1st year classes and the preparation beforehand consists of bread-and-butter artistic training, which means that 1st and 4th year students can be grouped together as those who have received “visual arts training”. The 4th years also take many classes from art history to modern art theory, but critique and talking about art must not have affected the visuo-spatial ability of art students. The results show the positive effects of visual arts training on spatial ability. Furthermore, they add onto previously discussed findings related to gender differences in spatial ability.

The mental rotation task used by the study was as previously described and gave participants ten minutes to answers 48 questions of that nature. The out-of-focus pictures task showed participants ten monochromatic, out-of-focus pictures of objects and asked them to guess what they were. The Gestalt task showed participants eleven incomplete drawings of objects and asked them to guess what the objects were. The embedded figure task first showed participants the drawing of a shape, and then asked them to find the same shape as it was embedded within a set of lines and other shapes. The drawing tasks mostly involved copying line drawings, but there were no time restrictions for these as opposed to the previous tasks. The accuracy and time it took for the participants to complete these tasks were used to assess their perceptual and spatial abilities. When first-year art students (who have had some art training) were compared with novices (who had received no art training), first-years outperformed novices in all of these tasks (Kozbelt, 2001, p. 714).

When the first-year art students and fourth-year art students were compared, the latter performed better in all tasks, but the statistical significance of the differences were low. Thus, Kozbelt grouped 1st and 4th year students into a single “art student” category and did further analysis based on this grouping. It is interesting to note however, that the only reversal of this trend occurred for the mental rotation task: “1st year art students do better than 4th year art students at the mental rotation task, with a mean z-score difference = .79, $F(1, 28) = 5.19$, $p < .05$.” (Kozbelt, 2001, p. 715). This deviates from all other results and could indicate that there is a temporal benefit to visual arts training: 1st year students who have more recently undergone hands-on visual arts training may have heightened visuo-spatial abilities compared to 4th years who may have specialized in various non-applied aspects of the visual arts, such as theory, history, writing, economics etc. However, the small sample size could have also exacerbated individual differences seen in visuo-spatial but gender is unlikely to be a confounding variable as the two samples have almost the exact m/f subject ratio: 1st year (m=5, f=12) vs 4th year students (m=4, f=9).

Kozbelt's analysis of gender-based differences in the perception and mental rotation tasks revealed that gender differences existed for both art students and novices, however "the numerical difference between novice males and females was [almost 5 times] larger (–0.21 versus –0.94) than that between art student males and females (0.35 versus 0.19)" (Kozbelt, 2001, p. 716). Thus, gender differences were more prominent in the students who had not received visual arts training. Additionally, a male-advantage in spatial ability would not be able to account for the novice versus art student difference, since "male novices outnumbered female novices 11 to 5 and female art students outnumbered male art students 21 to 9" (Kozbelt, 2001, p. 717). These results show that the male-advantage in visuo-spatial ability observed by other studies with non-artistic subject group is *not* observed for a subject group who has had visual arts training and practice, suggesting that visual arts training can reduce the male-advantage observed in visuo-spatial ability. The analysis also revealed that gender differences in visual perception and visuo-spatial ability decrease for individual with visual arts training, which could indicate that visual arts training has played a role in alleviating the gender difference.

Regression analyses reveal common visual processes in the three different kinds of tasks and unique variance in the drawing tasks, which allowed Kozbelt to hypothesize a mechanism for visual arts training to have impacted visuo-spatial ability:

It is hypothesized that the basis for this difference [between artists and non-artists] lies in artists' vast experience in meeting the task demands of drawing and other artistic activities. In particular, artists must be adept at the visual analysis and evaluation of three-dimensional objects and two-dimensional images in order to create correspondences between a goal plan for drawing, what is seen, and what has been drawn (Kozbelt, 2001, p. 718)

The perceptual and visuo-spatial advantages seem to be closely linked to the activity of drawing due to artists' extensive experience in visual interaction with objects and images during drawing. Thus, the advantage of artists over non-artists seems to arise from the way they perceptually analyze visuo-spatial information as well as how they *draw.* Kozbelt proposes an cognitive explanation for why this might be the case: "a way in which artists might be cognitively different is that their memory for visual materials may improve" (Kozbelt, 2001, p. 706). This hypothesis is supported by Kaufman's demonstration that improved working memory capacity does in fact correlate with improved visuo-spatial ability. Although Kozbelt's seminal study provides much evidence for the claim that visual art training improves spatial ability, potentially alleviating the gender gap in visuo-spatial ability, the limited scope of cognitive domains evaluated by the tasks undermine Kozbelt's ability to identify whether these advantages experienced by those who have had visual arts training are domain specific.

Chamberlain et al. aimed to replicate and expand upon previous research by Kozbelt's in order to advance the contemporary debate in the field and resolve the matter related to domain specificity of the advantages of visual arts training and practice (Chamberlain et al., 2019). The study explored the differences in visuo-spatial ability between art students (n = 42) and non-art (psychology) students (n = 37) at a university, but this time with a more comprehensive battery of visual-spatial and drawing tasks compared to those of Kozbelt in order to distinguish between top-down (improvement in cognition) and bottom-up (improvement in perception) advantages. These tasks included the original mental rotation task, the out-of-focus pictures task, the embedded-figures task, a multitude of line-copying based drawing tasks, as well as three unique cognitive tasks aimed at measuring top-down or bottom-up differences in visuo-spatial ability and perception:

The visual illusions task measured individuals' [bottom-up] differences in the strength of visual illusions with three illusions: the Ebbinghaus, Muller-Lyer, and Rod-Frame illusions. The Bistable Figure Task measured participants' [top-down] ability to manipulate their internal perceptual representations. The Navon Hierarchical Shape Task measured individual [bottom-up] differences in local and global visual processing (Chamberlain et al., 2019, p. 62).

The results showed that art students outperformed non-art students on all drawing measures (unsurprisingly), the mental rotation task, the embedded figures task and the bistable figure task (Chamberlain et al., 2019, p. 66). There were no statistically significant differences found between the two groups for tasks based on bottom-up perceptual processes. This indicates that the art students had an advantage over non-art students in their ability to mentally represent and manipulate images or objects, map them onto others and draw them—but not in their susceptibility to visual illusions, their recognition of visually occluded or obscured shapes and objects. This nuanced pattern of results indicate that "art students differ from non-art students in their ability to exert top-down control over attentional processing, but not in the phenomenology of low-level visual processing" (Chamberlain et al., 2019, p. 68).

These results add to a growing body of evidence that have found that artists' advantages over non-artists don't necessarily extend to all aspects of visual processing (Chamberlain et al., 2019, p. 59; Nodine et al., 1993; Winston & Cupchik, 1992). The studies suggest that artists might have better control over top-down exerted attentional processing of visuo-spatial information:

If one considers the overall pattern of results in the visual-spatial portion of the task battery, those tasks that isolate top-down influences on visual attention appear to be most facilitated among the art students, while tasks driven by bottom-up perceptual processing mechanisms appear largely equivalent between the two groups. This implies that task- benefits associated with artistic ability are a result of enhanced perceptual intelligence (top-down), rather than enhanced sensitivity for visual stimuli (bottom-up) (Chamberlain et al., 2019, p. 69).

Previous studies that lend support to this top-down perceptual mechanism have identified a measurable behavioral difference for individuals with visual arts training compared to those without: Nodine et al. compared the viewing patterns of individuals with and without visual arts training and found that visual arts-trained viewers were interested in the patterns and relationships among compositional elements, whereas untrained viewers focused more on individual objects and not on the relationships among pictorial elements when judging a visual composition (Nodine et al., 1993). These were reflected in their visual exploration patterns (indicated by % fixation time on certain areas) measured by visual fixation analyses (Nodine et al., 1993, p. 227).

The different viewing modality employed by arts-trained viewers enabled them "to restrain the natural tendency to focus on subject matter, and instead explore the order and dynamics of visual structure (Nodine et al., 1993, p. 227; Winston & Cupchik, 1992). This suggests a behavioral mechanism for how visual arts training could be affecting visual perception in a top-down matter: by enhancing the selectivity of working memory. Kaufman (2007) has shown that working memory capacity mediates visuo-spatial ability, but there is yet no direct evidence to show that enhancing the selectivity of working memory translates to an increased working memory capacity, which as discussed previously, correlates strongly with increased visuo-spatial ability. Further research is necessary to tie these lines of research together to show that working memory capacity can be enhanced by working memory selectivity, which would go to show that STEM success can be influenced by visual arts training.

A study by Vogt & Magnussen that compares the visual memory—although not *working* memory— of trained artists (n=9) and non-artist college students (n=9) from similar backgrounds indicate that selectivity in memory can indeed enhance memory capacity (Vogt & Magnussen, 2007). The two groups were shown various kinds of images on screens in two sessions and asked to recall the contents of these pictures after a short rest. The results show that the artists showed better memory for pictorial detail than the artistically untrained viewers for all picture types. Analyses of frequency and duration of the subjects' eye fixation patterns across images revealed that artists employ a different pattern of viewing than non-artists, consistent with Nodine et al. The behavioral difference in fixation duration and frequency match the definition of a "top-down exerted attentional control", which has been shown by past research to be the result of artistic training. The results of this study can inform future research specifically on the relationship between "selectivity" and "capacity" of working memory by suggesting that individuals could show variability in their ability to control what is stored in working memory due to a top-down difference in their visual perception modality, as is the case for non-working memory.

The elucidation of the various psychological mechanism that gives rise to the tangible effects of visual arts training on visuo-spatial memory have come a long way, and although the mechanisms have not yet been fully determined, there is enough evidence to show that visual arts training leads to increased visuo-spatial ability. This finding is enough to substantiate the initiation of research on pedagogical approaches that utilize visual arts training to impact STEM achievement. Drawing training could function as the starting point for educational approaches, as studies reveal the act of drawing to be the significant difference between individuals with and without visual arts training: visuo-spatial ability is impacted by visuo-spatial and perceptual advantages of art students over non-artists "to the extent that they are useful for drawing" (Kozbelt, 2001).

This is corroborated by the strong correlation of scores in drawing tasks with scores in mental rotation tasks of Chamberlain's student, implying that the findings of studies that compare artists with non-artists "may apply more readily to an activity (drawing) rather than a group of individuals (artists)" (Chamberlain et al., 2019, p. 68). Chamberlain goes so far as to suggest this explicitly: "it is especially pertinent for art students to develop their drawing skills in the service of a wider range of skills, which potentially include creative and analogical reasoning, the understanding of three-dimensional space, and perceptual and mental imagery ability" (Chamberlain et al., 2019, p. 60). These "wider range of skills" are useful interdisciplinarily and could form the foundation of a visual arts training supplemented approach to STEM education.

Effects of Visual Arts Training on STEM Success

Effects of visual arts training on students' performance in one area of STEM has been investigated, albeit narrowly (Walker et al., 2011). Walker et al. hypothesized that since both art and geometry entail visualization and mental manipulation of images, individuals with training in the visual arts would show superior performance on geometric reasoning tasks. Two groups of undergraduates, one majoring in studio art (m=4, f=14), the other majoring in psychology (m=1, f=17), were given a set of geometric reasoning tasks that required participants to rely upon visual working memory and the ability to engage in various spatial transformations. Participants were also given a verbal intelligence test. Both training in the arts and verbal intelligence were strong predictors of geometric reasoning, but training in the arts was a significant predictor even when the effects of verbal intelligence were removed (Walker et al., 2011, p. 24). These correlational findings lend support to the hypothesis that training in the visual arts may improve geometric reasoning and inform future studies that should aim to replicate these findings in other STEM areas or in other demographics. This study connects previous findings correlating visuo-spatial ability with STEM success and visual arts training with visuo-spatial ability, but it suffers from a similar problem.

Even though Walker et al., Kozbelt and Chamberlain et al. have studied the effects of visual arts training, their studies were not longitudinal and could not show the effects of visual art training *over time* on visuo-spatial ability and other ability domains. Their subjects were also exclusively adults at the university level, an age when artists and non-artists could differ considerably in their life styles, and hidden variables such as social or environmental factors that accompany an artistic vs non-artistic life style could influence their abilities. As such, a reasonable yet non-empirical assumption that underlies all these studies must be addressed: that it is *the visual arts training and practice* that yields artists an advantage in certain ability domains through top-down exerted attentional selectivity in working memory, and *not* other accompanying factors of an artistic lifestyle. Although these two factors empirically challenging to disentangle, it is critical that the latter be controlled in studies for educational interventions utilizing the visual arts to be justified. After all, an intervention cannot be expected to change the entire lifestyle of every student to match that of an artist.

A longitudinal study by Goldsmith et al. investigates the connections between visual arts training and geometric reasoning in a diverse group of 9th grade (pre-college) students. Growth in geometric reasoning in students engaged in intensive study of either the visual arts (m=24, f=11) or theater (m=12, f=17) were compared at three testing points: the beginning of 9th grade, end of 9th grade, and end of 10th grade (Goldsmith et al., 2016). The students were all from the Boston Public Schools, they took the same math classes, were from low socioeconomic backgrounds, about one third of them were Hispanic, one third Black and one third White and other (Goldsmith et al., 2016, p. 58). Thus, this longitudinal study was not conducted with predominantly White, college-educated, potentially rich and privileged individuals. The experimenters hypothesized that students engaged with visual arts training and practice would improve more in geometric reasoning than students engaged in equally intensive study of theater (Goldsmith et al., 2016, p. 56). Its results corroborate findings by Walker et al. that visual arts education and practice has a positive impact on geometric reasoning, and findings by Chamberlain et al. and Kozbelt that the advantages are domain specific.

A battery of tasks was used to measure students' performance in different ability domains. The geometric reasoning task was based on internationally recognized standardized tests; improvements were made to emphasize the measurement of geometric reasoning rather than geometric knowledge by simplifying certain vocabulary. An "artistic envisioning" task was employed to measure drawing ability, it consisted of timed still life drawing of objects. Four additional tasks were employed to measure visuo-spatial ability. The "mental rotation" task was as described earlier, but it utilized real objects rather than images of objects on paper and had a drawing component. The "abstraction" task asked students to sketch the negative space surrounding objects. The "flattening the space task" asked students to sketch a two-dimensional representation of a three-dimensional arrangement of objects. The "shadow projection" task asked students to predict where the shadow of an object would fall given different light projections. Although some of the visuo-spatial ability measures included drawing components, they were evaluated based on the accuracy of spatial representation and not on drawing execution.

Statistical analyses of the students performances show that all of the visuo-spatial tasks correlated with the art envisioning task, supporting the notion in the field that visual arts training correlates with visuo-spatial ability (Goldsmith et al., 2016, p. 64). The visual arts group performed better than the theater group in the first testing point, which agrees with the findings of Walker et al. However, the longitudinal aspect of this study allowed for the assessment of improvement in geometric reasoning of otherwise similar students based on whether they received visual arts or theater training. Results show that the "visual art group improved significantly more than the theater group from pretest [first testing point] to post2 [third testing point], $t(62)= 2.532$, $p= .01$" (Goldsmith et al., 2016, p. 64). This finding is critical in showing that a visual art based educational approach that supplements the normal curriculum correlates with improved geometrical reasoning of students. Of course, future research is necessary to investigate whether the visuo-spatial ability gains could translate to success in STEM fields other than geometry.

A secondary analysis of the data revealed that students whose drawings of a simple still life were extremely spatially disorganized performed significantly worse on the geometric reasoning assessment than students whose drawings were at least adequate spatial representations of the scene (Goldsmith et al., 2016, p. 56). The experimenters explain this by stating that the kind of visual-spatial thinking required in drawing and that required in geometric reasoning are very similar, and this finding supports the conclusion reached by Chamberlain et al., that the act of drawing underlies gains in visuo-spatial ability. What the experimenters realized though, was that some students (independent of their group) came in with good drawing skills and some came in with bad. Good drawers did better in geometry than bad drawers, and this *did not change over time* by training (Goldsmith et al., 2016, p. 65). That is concerning for two reasons.

The first one is that once pre-training drawing ability is controlled for, visual arts training and practice does *not* improve visuo-spatial ability or geometric reasoning. The study could not determine whether that is due to the limitations in instruction ability or limitations in the ability of students to receive instruction. Goldsmith et al. suggests that the overlap demonstrated between visual-spatial thinking in geometry and art could have educational implications for the teaching of geometry: development of visual-spatial thinking through the visual arts could support geometry learning for students who are not succeeding in mathematics classes. Research into the success of such educational interventions, controlling for student background and prior ability in drawing, is necessary to substantiate that suggestion.

The second concern is that there could be innateness or a tendency for visuo-spatial learning that educational interventions cannot alleviate. In this study for example, students picked what class they took: visual arts or theater arts. Thus, an individual bias towards the visual-arts could be a confounding variable: students who are more apt at spatial reasoning, who have strong visuo-spatial and perceptual abilities could have a higher affinity for visuo-spatial problems central to the visual arts. This sort of underlying problem permeates the field, including previously discussed research too: all subject groups consisted of individuals that have self- selected to undergo visual arts training. An important question that the field should aim to answers is what personal or environmental factors affect an individual's choice to practice visual arts over other disciplines. That is a formidable task, to establish the developmental framework of an interest in the visual arts. It is even more challenging to understand the underlying psychological mechanisms that connect visual arts training and practice with visuo-spatial ability, working memory capacity and STEM success.

However, this multi-modal developmental question is also an incredibly fruitful one as its effects would profound: it would revolutionize the field of education as we know it, change the relationship of the visual arts with the public and the state and impact the financial dynamics of the art circles.

Conclusion

Studies have shown that visual artists differ from non-artists in many ability domains, namely drawing and visuo-spatial ability (Chamberlain et al., 2019; Kozbelt, 2001). These two domains have shown to be interrelated, with advantages of visual arts training being were mediated by drawing ability (Chamberlain et al., 2019; Goldsmith et al., 2016; Kozbelt, 2001). The discussion of visuo-spatial ability, which is known to be malleable (S. Levine, 2020; S. C. Levine et al., 1999), is critical for contemporary discussion of educational approaches in STEM education, because visuo-spatial ability has been shown time and time again to predict STEM success (Ganley et al., 2014; Goldsmith et al., 2016; Kaufman, 2007; Stavridou & Kakana, 2008; Walker et al., 2011).

Investigation of the mechanism by which visual arts training affects visuo-spatial ability has revealed much and paved the path for future work. Working memory capacity was found to be a major underlying cognitive factor mediating visuo-spatial ability (Kaufman, 2007). Viewing strategies employed by visual-arts-trained individuals were found to increase their memory when compared to untrained individuals (Nodine et al., 1993; Vogt & Magnussen, 2007; Winston & Cupchik, 1992). Visual arts training could be altering an individual's visual perception modality by allowing them to exert top-down selectivity in their visual perception (Chamberlain et al., 2019). That in turn could be improving their visual working memory and thus explain the observed advantages in visuo-spatial ability. Though future work is necessary to support this mechanism, there is enough evidence in the field to substantiate preliminary visual art based educational interventions to supplement students in STEM education.

This literature review suggests that "drawing" should be the key aspect of such educational interventions, based on findings that show its instrumentality in developing artists' perceptual and visuo-spatial abilities (Chamberlain et al., 2019). Research in educational research at the end of the last century had yielded conflicting results about the advantages of visual arts training for improving visuo-spatial ability (Haanstra, 1996), but that did not deter the educational trend observed in the last two decades in the USA towards arts-based pedagogic approaches to supplement STEM education (Perignat & Katz-Buonincontro, 2019). Although psychological research on the mechanisms and potential benefits of visual arts based educational practices that could impact STEM success is only recently blossoming, the possible connection between the kinds of thinking required in the arts and in STEM fields holds potential for exploring innovative approaches to STEM education (Goldsmith et al., 2016, p. 58).

It is also worth mentioning that the research into other artistic activities that may promote visuo-spatial is necessary to answer the fundamental question of "why visual arts?"; when other art forms that require spatial representation but do not involve motor control in the same way, such as photography, or that perhaps require even greater motor control, such as dance, exist. There may also be semi-artistic activities, such as virtual reality navigation tasks, playing certain videogames or interactive visual experiences, that could activate similar cognitive domains. Tough these questions remain unanswered, the swathe of empirical evidence that connects visual arts training to improved visuo-spatial ability and thus STEM ability offers a point of entry for scientific inquiry into the mechanism by which many artistic and semi-artistic modalities may influence STEM success of future generations of students.

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