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ARTICLE
Using BioRender for Active Learning: Exploring Learning-Style Preference and Visual-Spatial Ability in Undergraduate Students

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Visual-spatial reasoning has been considered a predictor of performance success in STEM courses, including engineering, chemistry, biology, and mathematics.Little is known, however, about whether visual-spatial ability predicts success for non-STEM students in general education neuroscience courses. In the following study, we investigate how scores on tests of visual-spatial object rotation relate to student performance on illustrative and content exams in a large non-major undergraduate neuropharmacology course. To help students understand content visually, the course provided students with homework assignments that allowed them to create illustrations of lecture content using the online scientific illustration software, BioRender. Findings suggest that percent completion of BioRender assignments was a greater predictor of student performance than tests of innate visual-spatial ability. In addition, we show that visual learning style preference was not correlated with visual-spatial ability, as measured by the Purdue Spatial Visualization Test-Visualization of Rotations. Neither did learning style preference predict student success. The following paper suggests practice illustrating neuroscience concepts, or perhaps content practice in general, had a greater impact on student learning independent of learning style preference or innate visual-spatial ability.

Key words: Visual-spatial, Learning modalities, Biorender, Illustration, drawing, visualization, active learning, undergraduate neurobiology, neuropharmacology, higher education

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Neuropharmacology presents novel content that most courses college students, particularly non-Biology majors, are unfamiliar with upon entering higher education. These students typically lack prior mastery of concepts relating to neural pathways, receptor binding, dose-response, electrochemical conductance, pharmacodynamics and behavioral measures. Large lecture instruction relies on the presentation of two-dimensional images (2D), presented along with verbal or written descriptions, to help students develop a three- and even 4-dimensional (3D and 4D) mental model of neurophysiology and synaptic mechanism. Therefore, development of visual-spatial literacy is considered necessary to build mental models of scientific phenomena that inform higher order thinking (Milner-Bolotin and Nashon, 2012). Conceptually, neuropharmacology courses require students to be able to make predictions about how neurotransmitter levels and receptor populations change in response to a variety of ligands. Furthermore, an understanding of receptor binding and dose-response curves suggest expects that students can extrapolate how a change on a graph represents synaptic events. These tasks require visuo-spatial mental models of neuroanatomy and neurophysiology.

Our first goal in implementing this study was to determine if students with stronger visuospatial ability, defined as the capacity to understand and remember the spatial relations among objects, perform better on exam assessments (Lufler et al., 2012; Milner-Bolotin and Nashon, 2012; Sahiti and Stamp, 2022). To measure students' visual-spatial ability in our course, we tested students using the Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R), a widely used indicator of visual-spatial ability. The PSVT:R is a timed test that requires test-takers to mentally rotate 3D objects based on 2D illustrations of varying complexity, requiring both the ability to visualize the object and hold it in short-term memory (Bodner and Guay,1997). High PSVT:R scores have been shown to predict success in a wide variety of undergraduate STEM courses, including chemistry, physics, math, engineering, geology, geometry, medicine, dentistry, and radiology, as spatial problem-solving is required across these subjects (Liu et al, 2021; Margulieux, 2019; Berkowitz and Stern 2018;). It is not well understood, however, whether this relates to the same visual-spatial ability is required for establishing mental models used in the biological sciences (Milner-Bolotin and Nashon, 2012). Historically, men score higher on PSVT:R tests than women, suggesting that if PVST:R scores predict success in a course, then men have an advantage (Maeda and Yoon, 2016; Bartlett and Camba, 2023; Wang, 2017; Goldstein et al., 1990).

Our second goal was to provide a series of illustration assignments to see if practice, as measured by completion of these assignments, was related to performance on assessment tests. Previous undergraduate biology and neuroscience courses have employed drawing activities to improve student understanding of course content and improve model-based reasoning (Quillin and Thomas, 2015; Sahiti and Stamp, 2022; Wu and Rau, 2019). In our course, some students claim to enjoy hand-drawn assignments while others do not, stating that they are "not visual learners" or that they "can't draw". In mathematical modeling, the positive effects of drawing strategies were observed only for students that enjoyed drawing, while negative impacts were seen for students who had anxiety about drawing (Schukajlow, 2021). We wanted to know if neuropharmacology students with better visuospatial ability, who prefer visual learning, benefit more from visual learning activities. To test this, we employed the online software tool BioRender (Biorender.com) to assist students in creating high-quality, scientific biomedical illustrations for publication. BioRender provides a library of pre-made customizable elements common to biological sciences. Although the platform is widely used in academia to create images for scientific publication, we saw an opportunity to use BioRender as an education tool. We developed assignments that asked students to create illustrations in BioRender to reinforce course content. We did not intend for this limited number of assignments to improve student visuospatial ability.

Our third goal was to identify any relationships between student learning style preference and assessment performance. To explore this, we had our students complete the VARK survey. The VARK model helps students determine their learning style by categorizing their preferences into four primary modalities: Visual, Auditory, Reading/Writing, and Kinesthetic (Leite et al, 2010; Lehman, 2019; Fleming, 1995; Fleming 2014). Visual learners prefer to learn through illustrations, charts, graphs, and images, as opposed to written, experiential, or verbal content.

A recent study of medical student neuroanatomy showed that visual learning preference was a significant predictor of visuospatial ability as well as neuroanatomy comprehension (Ilyas et al, 2024). While undergraduate neuroscience courses are not as rigorous as medical neuroanatomy, there may be parallels as it relates to visual-spatial ability. Thus, the following study also investigates whether the percentage completion of BioRender-assisted assignments, PVST:R measures of visuospatial ability, and VARK measures of learning style preference, predict student performance on assessments of undergraduate neuropharmacology comprehension. In addition, we investigated potential relationships between visuospatial ability and visual learning preference.

MATERIALS AND METHODS

Our study sample consisted of 235 students enrolled in a large lecture non-majors undergraduate neuro-pharmacology course called Drugs and the Brain. This course satisfies a science and technology general education requirement for non-biology students. Sex was determined by self-report data provided by the Office of the Registrar (186 female and 69 male). The population consisted of 17 freshmen, 92 sophomores, 74 juniors, and 52 seniors. The enrolled majors of the student population varied widely across both traditional STEM and non-STEM disciplines but did not include any Biology majors. Student primary majors consisted of: (41) Public Health Policy, (25) Psychology, (24) Crim, Law and Society, (23) Psych and Soc Behavior, (20) Business Administration, (16) Political Science, (14) Computer Science, (12), and less than 10 students for each of the following: Undeclared, Cognitive Sciences, Business Economics, Sociology, Chemistry, Education Sciences, Psychological Sciences, Mechanical Engineering, Social Ecology, Urban Studies, English, Civil Engineering, Chicano/Latino Studies, Art, Environmental Engineering, Asian American Studies, Aerospace Engineering, Environmental Science, Drama, Philosophy, International Studies, Quantitative Econonomics, Earth System Science, and Film and Media Studies.

BioRender Assignments

We employed BioRender software (BioRender.com) to remove concerns about artistic talent in visual learning tasks. Students were provided an alternative to hand draw the identical assignments if they didn't have access to technology, but all students had computer access and chose to use BioRender. Students created free BioRender accounts by visiting the website, clicking on 'Sign up free' in the top right corner and filling out the form with their name, institutional email address, and a customizable password. After choosing their research area(s) (optional), they clicked 'Sign up' to create their account. Free users are able to create up to 5 illustrations with full access to BioRender's individual icon library. Students can increase their free illustrations in Biorender by deleting their previous illustrations. Thus, the students' use of BioRender in this study can be replicated without cost. Although we only used the free plan, Premium BioRender Plans for Academia may be purchased and would include the following: unlimited illustrations, unlimited objects per illustration, high-resolution export (png, jpg, pdf), transparent background with no watermark, permission to publish in journals, custom icon requests and access to all icons, biobrushes and pre-made templates.

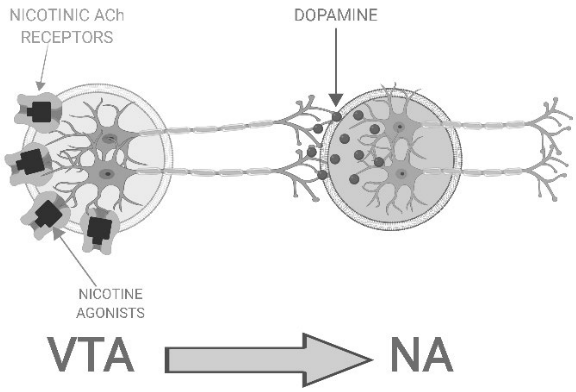
During the 10-week course, students completed six BioRender illustration homework assignments covering the following content: 1. The lobes of the brain and associated functions, 2. Receptors and neurotransmitters of the autonomic nervous system and the mechanism of tetrodotoxin on electrochemical signaling. 3. Synaptic mechanisms and postsynaptic receptor response to chronic full agonist and antagonist ligands. 4. The influence of nicotine on VTA dopamine neurons projecting to the nucleus accumbens. 5. Psychostimulant use and the dopamine hypothesis of psychosis. 6. Behavioral screens for anxiolytic drugs.

Students completed their illustrations in BioRender and submitted their completed illustrations to Canvas as an assignment upload. Following the Canvas deadline, the instructor reviewed the assignment answers in detail with students in the following lecture. Below are examples of assignment prompts and student work (Figure 1) created using BioRender templates: https://app.biorender.com/biorender-templates).

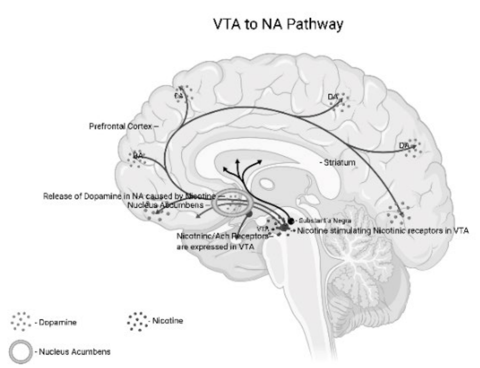
Example Prompt 1:

For this assignment I would like you to illustrate a group of dopamine neurons projecting from VTA (Ventral Tegmental Area) to NA (Nucleus Accumbens). 1. Locate where

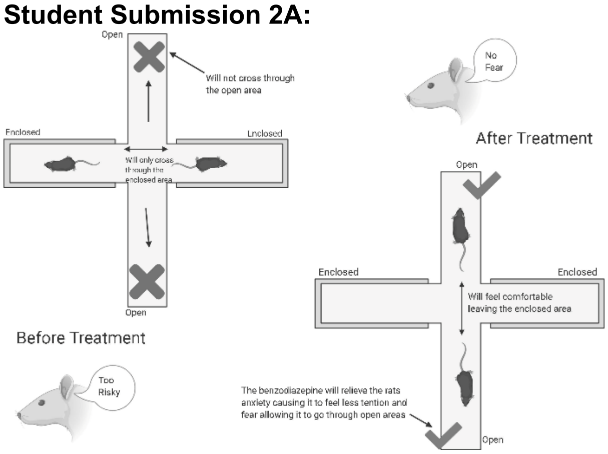
Student submission 1A:



Student submission 1B:



Student Submission 2A:



Student Submission 2B:

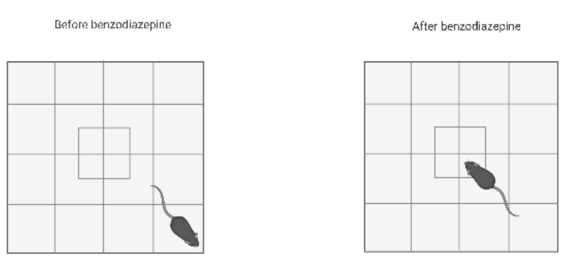


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Figure 1 Examples of student work in response to Prompt 1 and 2 (above).

Nicotinic receptors are expressed on these neurons 2. Illustrate the agonist nicotine stimulating the nicotinic receptors. 3. Show the release of dopamine in NA caused by the nicotine.

Example Prompt 2:
For this assignment I would like you to illustrate a rat's behavior both before and after treatment with a benzodiazepine. Find the correct "behavioral" task on BioRender (you may want to use the "ungroup" button on the top bar to move the rat) in order to illustrate the before and after drug behaviors.

Assessments
Content Pre-Test
A diagnostic pre-test consisting of ten comprehensive illustration questions was given on the first day of lecture based on the expected course learning outcomes. Examples of pre-test questions include the following:

- Draw a neuron and label the dendrites, axon and presynaptic terminal.
- Draw a synapse and label the reuptake transporter.
- Draw a hypothetical dose-response curve and label the X and Y axis.

Post-Tests: Illustration Scores
A diagnostic post-test score was determined from illustration questions that appeared on three course content exams. Each exam included illustration questions that incorporated concepts from the pre-test but challenged students using higher order Bloom's levels of application and synthesis to prevent a ceiling effect. None of the post-test illustration questions were identical to BioRender assignment prompts. An example of a of post-test illustration question is given below:

> Draw both a dopamine synapse in the NA and a regulatory GABA synapse. Show the following: a.) The mechanism of heroin action (morphine) on relevant receptors in both synapses, b.) label any region of potential receptor downregulation following chronic heroin use with down arrows, label any region of receptor upregulation following chronic heroin use with an up arrow, c.) additionally, show the mechanism of cocaine in the correct synapse.

Content Exam Scores
Content understanding was further determined using two formal exams consisting of multiple-choice questions that assessed student achievement of course learning goals. Some of these multiple-choice questions related directly to course content practiced in the BioRender assignments.

Purdue Spatial Visualization Test
Students were given a timed version of the Modified Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R) to determine whether assessment scores influenced innate visual spatial ability (Guay, 1977; Branoff, 2000; Maeda and Yoon, 2013). The Purdue Spatial

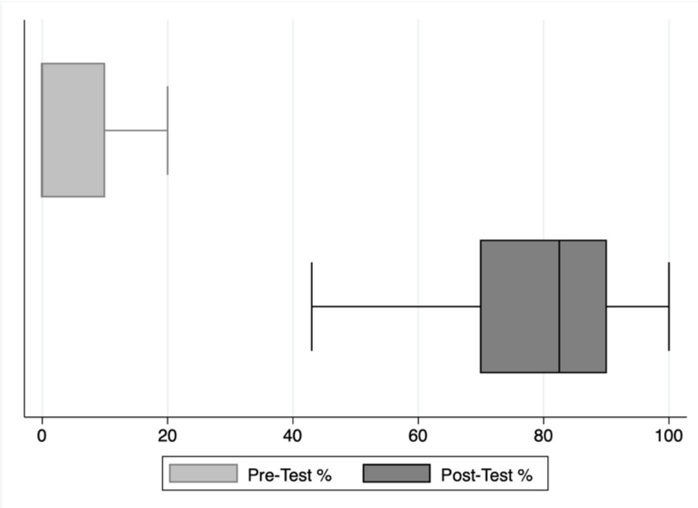

Figure 2. Pre-test (first day of class) and Post-test (exam assessment) scores.

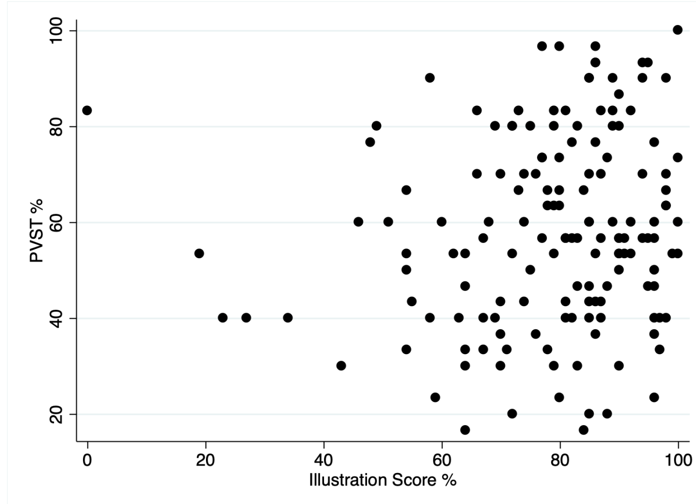

Figure 3. The relationship between Exam Illustration Score (%) and PSVT:R (%).

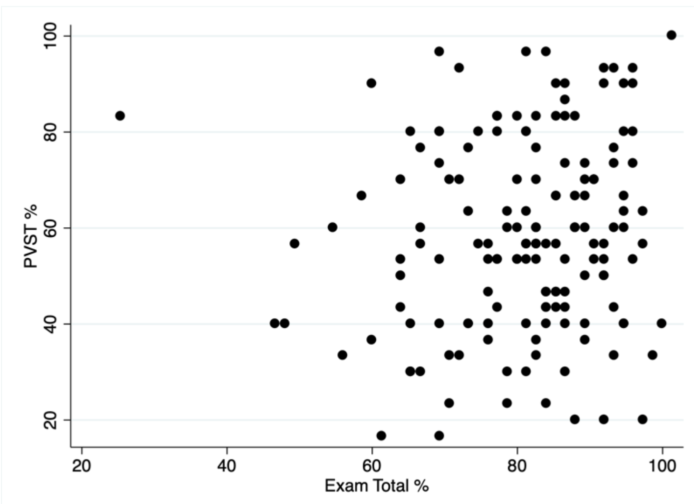

Figure 4. The relationship between Exam Score Total (%) and PSVT:R (%)

	PSVT X Illustration Score	PSVT X Content Score	Bio Render X Illustration Score	BioRender X Content Score
Coef.	.161086	.1909163	.3824596	.528731
Std. Err.	.0957529	.1344071	.0622678	.0892091
t	1.68	1.42	6.14	5.93
P>|t|	0.095	0.158	0.0001	0.0001
95% Conf. Interval	-.0281126 - .3502846	-.0746593 - .456492	0.2594627- 0.5054564	0.3525173- 0.7049447

Table 1. Column 1 shows the relationship between PSVT:R score and illustration assessment scores (illustration questions). Column 2 shows the relationship between PSVT:R score and Content exam score (multiple choice questions). Column 3 shows the relationship between BioRender assignment percent completion and Illustration questions. Column 4 shows the relationship between BioRender assignment percent completion and Content exam scores.

Visualization Test - Visualization of Rotations (PSVT: R) is a spatial ability test designed to assess an individual's capacity to “generate, retain, retrieve and transform well-structured visual images” (Lohman, D.F., 1996) particularly focusing on rotations. The timed test presents students a series of 2D illustrations representing 3D shapes and asks them to identify what the shape would look like if it were rotated in a specific direction. They are provided four illustrated options and must imagine the presented object rotated to make an informed decision on which option is the correct representation of the rotated object.

Learning Modalities

Students were given the VARK test to identify their learning preference as it relates to visual, auditory, or kinesthetic learning. These preferences aim to capture individuals' preferred modes of receiving and processing information for effective learning. The test asks students a series of questions about how they would respond to a variety of different situations to assess their learning preference. For instance, when asking for directions to a new location, the student may prefer a map (visual), a step-by-step verbal description (auditory), written directions (reading) or perhaps experiential information (kinetic).

Student Survey

At the end of the course, students were surveyed to answer questions about their experience using BioRender as an educational tool. This was a qualitative survey collecting student written feedback. Student written responses were quantified as agreeing with (responding positively) vs neutral/disagreeing with the following questions:

- Do you feel that BioRender helped you learn key scientific concepts?
- Do you think BioRender helped you better visualize scientific concepts?

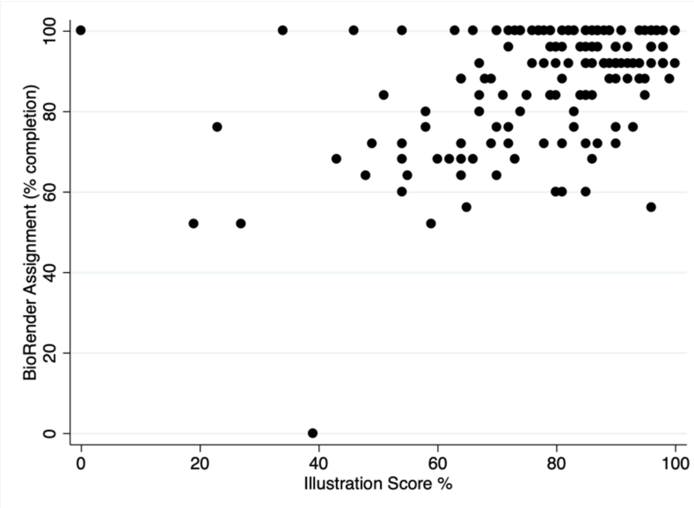

Figure 5. The relationship between illustration exam scores (%) and BioRender use (assignment percent completion). A significant association was observed (p < 0.001).

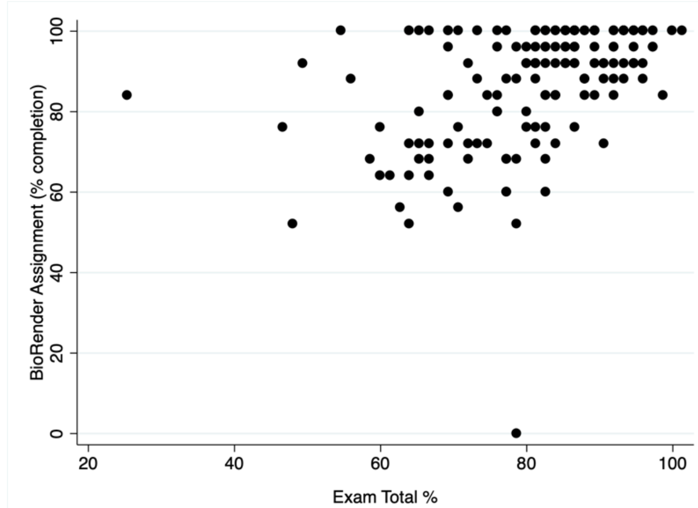

Figure 6. Relationship between Exam Total (percent correct for multiple-choice content questions) and BioRender Assignment percent completion). A significant association was observed (p < 0.001).

- Do you feel that using BioRender encouraged you to study scientific concepts?
- Would you prefer to learn from figures via an online textbook or from making figures in BioRender? (This was positive if preference was for BioRender)
- Do you believe students would benefit from using BioRender in another science course?

Statistics
All data was analyzed using Stata Statistical Software. PVST:R scores for male and female students were compared using a two-sample *t*-test. Similarly course multiple choice and illustration scores for male and female students were compared using a two-sample t test. The relationship between PVST:R and course assessments was analyzed using a linear regression Similarly the relationship between BioRender assignment percent completion and course assessments as well as VARK test scores and course assessments were analyzed using linear regression.

RESULTS

Overall Student Learning (Pre vs. Post)
Analysis of the pre and post-test illustration scores revealed a substantial gain in student performance. Pre-test scores exhibited a mean of approximately 10%, indicating a low baseline understanding of basic neuroscience and neuropharmacology concepts. In contrast, post-test scores demonstrated a mean of around 83% (Figure 2). This significant increase demonstrates significant improvement in student proficiency in visual-spatial concepts following completion of each assessed section of the neuropharmacology course

Purdue Spatial Visualization Test
There was not a significant relationship between student scores on the Modified Purdue Spatial Visualization Test-Visualization of Rotations (PSVT:R) and the Illustration Score, suggesting that a student's ability to represent scientific concepts visually is not influenced by visual-spatial ability (Figures 3 and 4, Table 1). PSVT:R did reveal gender results consistent with previous findings. Males (Mean = 66% ± 3) significantly outperformed Females (Mean = 55% ± 2, p < 0.003). However, increased PSVT:R scores among men did not predict higher course success or performance on illustration or content exam scores. In fact, female students scored significantly higher on both multiple-choice content questions (Female Mean = 82% ± 0.9, Male Mean = 77% ± 2.4, p < 0.005) and illustration questions (Female Mean = 80% ± 1.5, Male Mean = 74% ± 3.1, p < 0.03). Thus, females performed better on course assessments overall.

Biorender Completion and Student Performance
We observed a strong relationship between BioRender assignment completion and performance on both illustrated exam questions and multiple-choice content questions (Figures 5 and 6, Table 2). No differences between Male and Female students were observed for BioRender percent completion (p = 0.4). The content of BioRender assignment prompts related directly to a subset of content multiple-choice questions and provided students ample practice answering Illustration questions. Exams were designed so that the same prompts on the BioRender assignments were not used for illustrated exam questions, to control for rehearsal effect. Findings showed that time spent on visual tasks using BioRender was a better predictor of student success than innate visual-spatial ability (Table 1).

VARK Learning Preference
None of the four learning modality preferences determined by student VARK (Visual, Auditory, Reading or Kinetic) scores correlated with PSVT:R scores (V (p = 0.278) A (p = 0.575) R (p = 0.606) K (p = 0.834)). Thus, VARK-informed student preference for visual learning was not related to visual-spatial ability. Despite predominant learning preferences, there was also no significant relationship

Percent Students responding positively	Question
89%	Do you feel that BioRender helped you learn key scientific concepts?
94%	Do you think BioRender better helped you visualize scientific concepts?
69%	Do you feel that using BioRender encouraged you to study scientific concepts?
76% (Chose BioRender)	Would you prefer to learn from figures via an online textbook or from making figures in BioRender?
86%	Do you believe students would benefit from using BioRender in another science course?

Table 2. Summary of qualitative survey responses.

between student performance on course content exams (V (p = 0.842) A (p = 0.854) R (p = 0.178) K (p = 0.555)) or illustration assessments (V (p = 0.290) A (p = 0.410) R (p = 0.476) K (p = 0.941)), suggesting that no single learning style preference was not a predictor of student performance onneuropharmacology assessments in our course.

Student surveys revealed that 94% of students reported BioRender helped visualize scientific concepts and 89% felt they had stronger learning gains as a result of assignment completion. Thus, it seems that the percentage of completing BioRender assignments supported student understanding of the course content independent of self-reported learning style preference or innate visual-spatial ability.

In Table 2, we surveyed the students of the sample by asking qualitative questions regarding BioRender when they were towards finishing the course. The majority of students felt that BioRender helped them to learn and visualize key scientific concepts. In addition, BioRender encouraged students to study more with 69% of students responding positively on the Likert scale. The majority of students preferred BioRender to an online textbook and agreed to use it in future classes.

Examples of student survey responses:

- *I liked how interactive and hands-on it was. Especially for those of us who aren't artistically inclined. The pre-drawn diagrams really helped in terms of learning and visualization.*
- *I enjoyed that everything we needed to diagram could be used with any features on biorender that did not need to be drawn.*
- *I believe that it helped me learn key scientific concepts because after I had finished creating a Biorender for each assignment, I had a better understanding of what concept it was covering along with its relation to the course.*
- *I feel like it did help me for most of the concepts because I had to remember and actually place where certain items go. I think it helped me visualize the diagrams.*
- *Biorender definitely helped me visualize scientific concepts. It provides another model to look at other than models shown in class. They provide more professional-looking images rather than hand drawings to base class material off of, and the creation of these models help to learn these concepts.*
- *I would choose to use Biorender in the future because it was fun to use, and in that way it makes learning fun. It would also be useful to use to create my own models if I ever needed them to demonstrate to others.*
- *I know it is meant specifically for science--it's even in the name: "Bio"--but it would be very interesting to see if it could be extended to other subjects, such as economics, or any other subject that contains visual pieces to encourage learning.*

DISCUSSION

Visual-spatial ability is often a predictor of success in some STEM disciplines, but it does not appear to determine student success in this neurobiology course. Furthermore, while many students claim they are not visual learners or do not prefer visual learning activities, our data suggests they still benefit from greater percent completion of visual activity assignments. Using software programs like BioRender to assist visualization may alleviate some of the anxieties associated with artistic ability, as evidenced by positive student responses.

Our findings suggest that greater percent completion of BioRender, or more practice visualizing concepts, may play a larger role in understanding content than individual innate visual-spatial abilities. Like many studies utilizing PSVT:R, males in our class scored higher on the PSVT:R than females (Yoon, S. Y., and Mann, E. L. 2017). Females did better than males, however, on both illustrative or multiple-choice content assessments, indicating that higher PSVT:R scores are not a reliable predictor of success in neuroscience courses. We observed that increased percentage completion of BioRender activities was positively correlated with student performance on assessments. Active learning has been shown to improve student performance in higher education STEM courses (Freeman, S. et al, 2014). We cannot, however, conclusively claim that improved performance can be solely attributed to BioRender activities, especially as there were only six assignments over a 10-week course. It is more likely that students who completed more BioRender assignments also studied harder in general. In addition, we cannot know for certain whether motivated students may have sought additional information beyond class lectures to enhance their learning beyond BioRender assignment completion. Rather, student success in this neuropharmacology course may be attributed to individual determination.

Survey responses highlight that BioRender provided a unique and enjoyable platform for practicing visualization, which potentially aids in comprehending complex neuropharmacological and neuroscientific mechanisms engagingly and effectively. Consistent with other studies, our findings show that student preference for visual learning styles does not directly correlate with improved performance on visual tasks, such as illustrating (Lehman, M. E., 2019). This suggests no relationship between declared learning style preferences and actual achievement of learning goals. Further research is warranted to explore the nuances of concept visualization and its implications for future neuroscience instruction.

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