Inclusivity for Visualization Education: A Brief History, Investigation, and Guidelines

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Abstract

Diversity and inclusion are currently very trendy themes in higher education in science, mainstream culture, and the visualization community. However, the study of diversity with respect to spatial cognition has a long and rich research history extending far beyond the birth of the visualization community. In this brief study, we present a short historical overview of research on the topic of gender diversity and spatial cognition that dates back to the 1940s. We follow this with a small investigation of gender bias in our own data visualization classroom for university students studying computer science. Finally, we round this overview up, with concise recommendations on how to make the visualization classroom more inclusive to support diversity. We believe this educational paper provides a convenient introduction and overview to the topic of diversity in the visualization classroom.

CCS Concepts

•*Human-centered computing* → *Visualization theory, concepts and paradigms; Empirical studies in visualization; Visualization design and evaluation methods;*

1. Introduction

Diversity and inclusion have become more and more important in several fields. The main goal of this study is to address the topic of diversity and inclusion in the visualization community. In particular, we aim to give an overview of studies on diversity concerning spatial cognition and improve issues related to this subject. To get a better understanding of the impact of possible bias in visualization education, we investigate gender bias in data visualization class and evaluate the computer science students' scores. Additionally, we provide recommendations on how to make the visualization classroom more inclusive, supporting diversity and inclusion. The contributions of this paper are:

- A compilation of the historical study of gender bias in spatial cognition.
- The reporting of student scores from a data visualization class, focusing on gender bias.
- To provide a list of recommendations for visualization teachers, helping cater to a more diverse and inclusive classroom.

We start with a brief history of research on spatial cognition diversity with respect to gender. This is followed by a small investigation of evidence of gender bias in a data visualization course. This is followed by recommendations for inclusion in a visualization classroom.

2. A Short History of Diverse Cognition

The study of spatial cognition and perception with respect to gender has a long history dating back to the 1940s. Spatial ability is the capacity of imagining the shape of an object, its dimensions, co-ordinates, aspect ratio, movement, and geography. Picturing an object being rotated in space, turning around an obstacle and seeing things from a three-dimensional view can be included in the description of spatial ability [PP03].

1940s: In 1943, O'Connor uses a performance test called the "Wiggly Block" and discovers that almost 25% of females outperform the average of males in spatial ability [O'C43]. The earliest research paper reference we found on the topic dates back to 1943.

1950s: Guilford [Gui56] designs seven tests including spatial visualization, spatial orientation, and perceptual speed to assess a diverse tendency factor or primary mental ability. Results indicate that scores for females are significantly lower than scores of males in spatial visualization and spatial orientation. In contrast, females perform better than men in a perceptual speed test however the findings are not conclusive in that participants represent their gender.

1960s: In one study from 1960s, 104 males and females are given the Identical Blocks Test, as a standard test of spatial visualization, developed by Stafford in 1961. Results suggest that a gender-linked recessive gene may affect spatial abilities. Also, test scores demonstrate that females' scores are significantly lower than males [Sta61].

1970s: The right hemisphere plays a key role in spatial, holistic

cognitive processing, and handles visual and tactile spatial processing skills. An experiment with 200 boys and girls between 6 and 13 years of age demonstrates that the right hemisphere of boys is powerful in processing non-linguistic spatial information by about age 6 [Wit76]. Conversely, the right hemisphere in girls is not spatially developed even by the age of 13. These outcomes indicate that boys have greater hemisphere specialization and there is a gender dimorphism in the neural organization related to spatial cognition. The outperformance of males to females on many spatial tests is related to neural dimorphism. Spatial ability is connected to gender chromosomes and testosterone. Genetic and hormonal agents are the factors of neural dimorphism for the two gender [Wit76].

Research by Waber [Wab76] indicates that gender difference in adolescence has benefits for males with respect to spatial ability. He reveals that early maturers score lower on spatial ability tests than late maturers. Since puberty occurs earlier in females than in males, adolescent females are expected to have poorer performance on the spatial test.

1980s: Sanders et al. [SSD82] indicate that male performance is higher on a task that required subjects to mentally rotate three-dimensional arrays of cubes. Gilmartin and Patton [GP84] test college students and undergraduates to study the student skills with cartographic illustrations conveying geographic information. The gender based differences are observed in the younger age groups, where males outperform females and map use scores for females and boys are almost similar between college students. Research by Gilmartin [Gil86] investigates the effect of mental imagery on recall of spatial information and whether there is gender-based differences in ability to employ such a visualization technique. Subjects in three different groups are given maps with geographic text, illustrated with text and mental images of the text to read. Outcomes of the research indicate that gender has a significant impact on recall of spatial relationships where men score higher than women on reading the text with maps.

Dr Camilla Benbow, a psychology professor at Iowa State University, scanned the brains of more than a million males and females to examine their spatial ability and reports the distinction between gender is visible by the age of four. She finds that while females are successful at perceiving two dimensions in the brain, males have a better ability to perceive the third dimension [PP03].

Dr Benbow and Dr Stanley [BS83] test a set of talented children and discover that males outperform females at spatial mathematics by 13 to 1. Males can build a block building from 2D plans faster and easier than females. Males can predict angles precisely.

Beatty and Tröster [BT87] perform a survey of 1800 undergraduate students indicating that males could locate targets on a US map more accurately than females. A group of 202 male and female college students are tested by Chang and Andes [CA87] to investigate gender differences when reading reference and topographic maps. Results indicate that males outperform females in reading reference and topographic maps. The gender difference in mental rotation ability was, in 1989, the largest cognitive gender difference documented in the literature [Hal89].

3. Diverse Spatial Cognition in Popular Literature

We highlight some findings from a popular book [PP03] on the subject of spatial cognition with respect to gender.

1990s: A perspective on gender differences in spatial ability is published by Goldstein [GHM90]. He supports that males outperform females on spatial ability tests. However, his study also indicates that females' spatial skills may be masked due to lower confidence in their ability. If the confidence level of females could be lifted through experiments, their performance on a timed test might be identical to that of males. Males outscore females in spatial ability by a ratio of 4.1 on three-dimensional video tests. Spatial ability also enables a man to rotate a map in his mind and understand directions. The spatial field in his brain can store this information for future events. Research indicates that a man's brain can measure speed and distance to understand when to change direction [PP03].

Reading maps and understanding current location are related to spatial ability. Brain scans demonstrate male's most powerful ability spatial ability is situated mainly in the right brain of men. Spatial ability is located in both women's left and right brain hemispheres. However, most women have limited spatial ability. Only 10% of them have spatial abilities as dynamic as men according to Pease *et al.* [PP03].

The anatomy of Albert Einstein's brain was examined and compared to the preserved brains of 35 men and 56 women with average intelligence by Dr Sandra Witelson with other scientists at McMaster University [Wit76]. It was found that the spatial area of Einstein's brain, connected to his mathematical skills, is 15% larger on both sides than in average men and women.

In males, the right brain improves faster than the left brain and develops more connections with-in itself and fewer connections with the left brain. In females, both sides of brain improve at a equal speed which provides females with a more diverse range of skills. They also have more connections between left and right through a thicker corpus callosum which results in a tendency of females to be more ambidextrous than males. Many more women have difficulty identifying their left hand from their right.

Pease *et al.* [PP03] state, "Testosterone hormones inhibit the left-brain growth in boys as a trade-off for greater right-side development, giving them a better spatial ability for hunting. Studies of children between the ages of five and eighteen show that boys outstrip girls in their ability to move a beam of light to hit a target, reproduce a pattern by walking it out on the floor, assemble a range of three-dimensional objects and solve problems requiring mathematical reasoning. All these skills are located mainly in the right brain of at least 80% of men and boys".

Dr D. Wechsler develops IQ tests to remove sexual bias against men or women during spatial tests. People from cultures of primitive races to developed city residents are examined. Findings indicate that although women have slightly smaller brains, women exceed men in intelligence being around 3% smarter than men. When participants are asked to solve maze puzzles, men outperform women, scoring 92% without factoring in culture [PP03].

The British Cartography Society declares that half of its members are female, and maps are designed and edited by women as

well. British cartographer Alan Collinson states, "Map design is a two-dimensional task in which women are equally as capable as men". Alan Collinson adds that the most women face challenges when reading and navigating with the map because 3D perspective is required to navigate a route. Tourist maps have a 3D perspective. Thus trees, mountains, and other landmarks are featured on such maps which support women to perform better when reading the maps. His study also indicates that men have the ability to cognitively turn a 2D map into a 3D view in their mind, but most women don't seem to be able to do this [PP03].

Woman develop the spatial ability on both sides of the brain thus this may interfere with speech function. If a woman is given a street directory, she will stop talking before she turns the guide around. Whereas men will maintain speech. However, he will turn the radio off because he can-not manage to auditory processing while he is engaging his map reading abilities [PP03].

Practice and recurrence of a task increase brain connections. As an example, brain mass of a retired person who has nothing to do decreases over time. Whereas active intellectual interests protect brain mass and even improve it [PP03].

4. Diverse Spatial Cognition in Visualization Literature

The impact of cognitive abilities on the understanding of visual designs and what features of the visual designs influence users' understanding are considered unsolved problems. Velez *et al.* [VST05] aim to study spatial ability in a varied subject group to examine subjects' perceptions of complex visualizations. Velez *et al.* [VST05] contribute a basic visualization test experiment to assess comprehension and difficulty when visualizing spatial ability and report several outcomes from the experiment.

4.1. Challenges in Visualization Understanding

Classic 2D visualizations feature 2D slices and 3D volumetric orthographic projections. Research indicates that projection and slice-based visualizations are not ideal for shape understanding [Tor03] and comprehension of 3D space layout [RLF*98]. Therefore, combining 2D and 3D methods, cross sections or orthogonal projections unified with 3D position references are suggested.

Spatial ability is interrelated to skills involving the retrieval, retention and conversion of visual information from a spatial source [Hal00]. Researchers sub-divide the concept of spatial ability into more specific factors to help understanding. Six spatial factors are described by Kimura [Kim00] and can be identified by experimental assessment. These are: spatial orientation, spatial location memory, targeting, spatial visualization, disembedding and spatial perception.

4.2. Visualization Comprehension

Rizzo *et al.* [RBM*01] studies subjects that have difficulty with the Shepherd and Metzler [SM71] mental rotation test. Some users can develop their mental rotation ability through training in a VR environment. Gender differences in 3D virtual environment navigation is studied by Czerwinski [CCTR02], [Tor03]. Their results
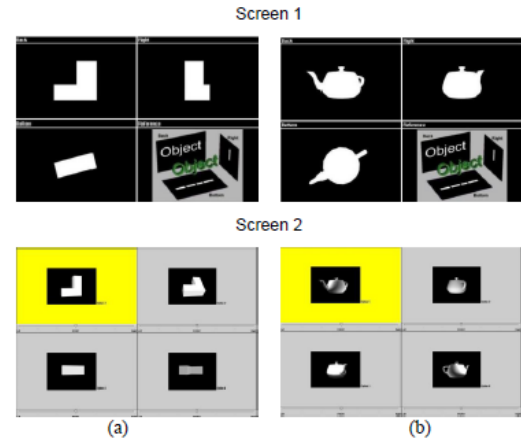

Figure 1: *Two object examples used in a visualization test. The figures in Screen 1 show the orthogonal projections and Screen 2 shows four possible answers. The correct answer appears highlighted [VST05]. Image courtesy of Velez et al. [VST05]*

indicate that larger displays and a broad field of view enhanced female performance in navigation tasks and was comparable to male performance.

An experiment is designed to assess a person's ability to understand visual designs and define how this ability is related to spatial skills. Velez *et al.* [VST05] describe an experimental method that focuses on fundamental visualization tasks by designing a simple visualization test that requires participants to form a mental picture of a 3D object based on its 2D projections. The test design is simple enough for inexperienced users and resembles standard spatial ability tests. The goal is to understand what makes a 3D visualization challenging based on the features of the objects and their visualization presentation.

A total of 56 students, half of them female, aged between 18-31 studying or graduated from US University participate in the study. Each experimental session takes approximately two hours. In the first hour, participants are given five paper-based cognitive factor tests. After the paper tests, computer-based visualization tests are administered. Subjects are seated in front of desktop computers on which the orthogonal projection test is administered and are expected to answer 38 questions. Figure 1 provides two examples used in the visualization test.

Data from the experiment is analyzed based on gender for visualization ability for each of the spatial skill tests. The result indicates that males perform distinctly better on the visualization test than females. Velez *et al.* [VST05] determine that geometric objects, the number of original and hidden surfaces, edges and vertices relate to accuracy, and that low spatial ability participants are able to understand only basic geometrical objects such as cubes and cones.

Velez *et al.* [VST05] summarize some results from the study.

- Spatial ability diversity in the population is quite large. They argue that they examine a large enough subject pool.
- Understanding a visualization is related to spatial ability. The level of spatial skill can help to explore the reasons behind com-
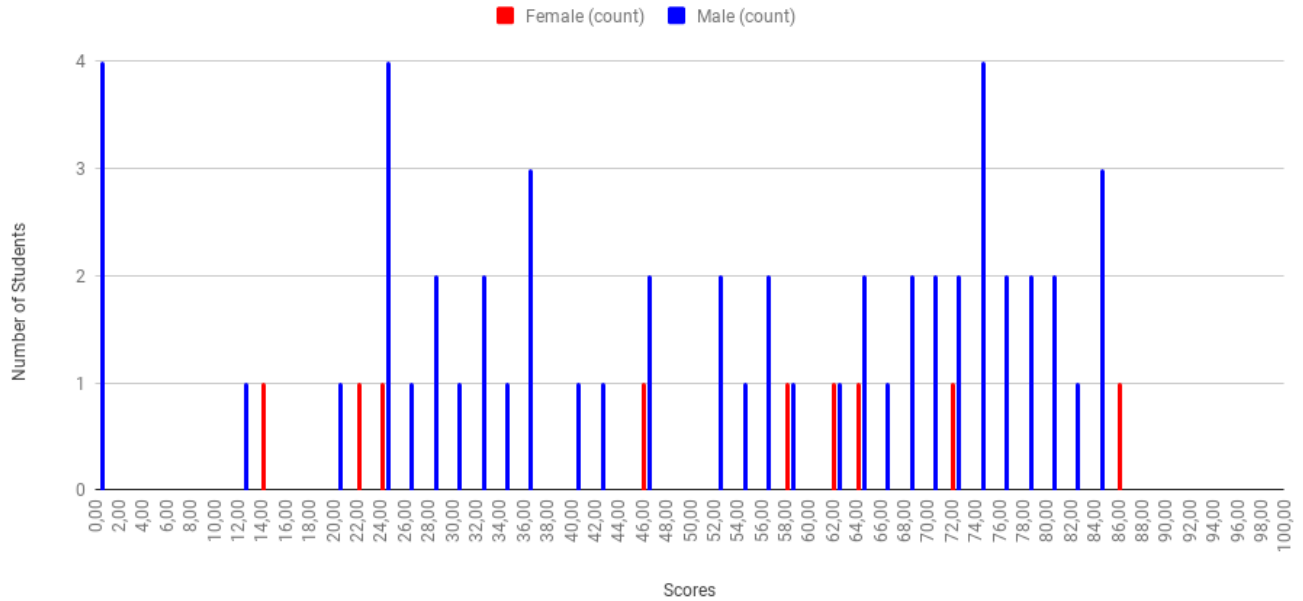
Figure 2: *Histogram of the Data Visualization Exam scores in 2018 includes the average score for males (50) and females (50). Gender is indicated.*

prehension problem by comparing distinct comprehension mistakes. Spatial ability can also be used to classify the population so that visualizations can be customized for different spatial ability groups.

- Time is not related to visualization accuracy. Time to understand projections does not affect accuracy in a visualization test. Using time to assess the properties impact on understanding of visualization is not recommended.
- The number of geometric properties influences visualization accuracy and examination time. This result indicates that if an animation is aimed for the general population the speed of animations for complex objects presented can be a strong influence.
- The hidden geometric properties in the visual representation of object influence the accuracy of visualization. Hidden objects in the visualization make the image difficult to understand for a user with low spatial ability. Rotating the object will enhance understanding for a user.
- Small rotation is difficult to detect. To identify small changes of rotation with small angles when comparing two objects is a difficult task.

5. Investigating Evidence of Gender Bias in a Data Visualization Class

Surprised and interested in the gender-based diversity in spatial cognition research literature, we decided to look for evidence of gender bias in the data visualization module at Swansea University, Wales. The Data Visualization module has been taught to third-year undergraduate and master level students since 2006. The course includes two lecture hours and a one-hour lab session each week during the semester. Many students enrolled in this course are from overseas countries, and most of the class consists of male students, about 85% of the class, as do all computer science classes at Swansea University.

The assessment consists of one exam at the end of the semester, and two assignments, one of which is focused on information visualization and the other on scientific visualization. Students are provided with a data set and asked to create and explain at least five unique visual designs using existing data visualization tools for the first assignment. For the next assignment, students must modify source code given by the lecturer and use this code to produce volume visualizations with the help of existing volume renderers and describe how they obtain the visual representations. In addition to the programming aspect, they also use a volume data set provided to them to use volume visualization software such as ParaView [Par] and Inviwo [Inv]. Both assignments are marked by focusing on students' visual designs and the description of each image.

We aim to investigate for evidence of gender bias and its impact on students in our class by comparing scores for both genders. We produce six histograms for this investigation. Three histograms consist of the 2018 exam and coursework assessment results. The other three histograms represent five years' worth of exam and assignment assessment results from 2013-2017.

2018 Exam Results

We classify students according to gender. The histogram for 2018 exam results (See Figure 2) displays the minimum and maximum exam scores as 0 and 86 respectively. Only seven students, one of them female, score higher than 80 (In the UK, scores above 70 are considered excellent.).
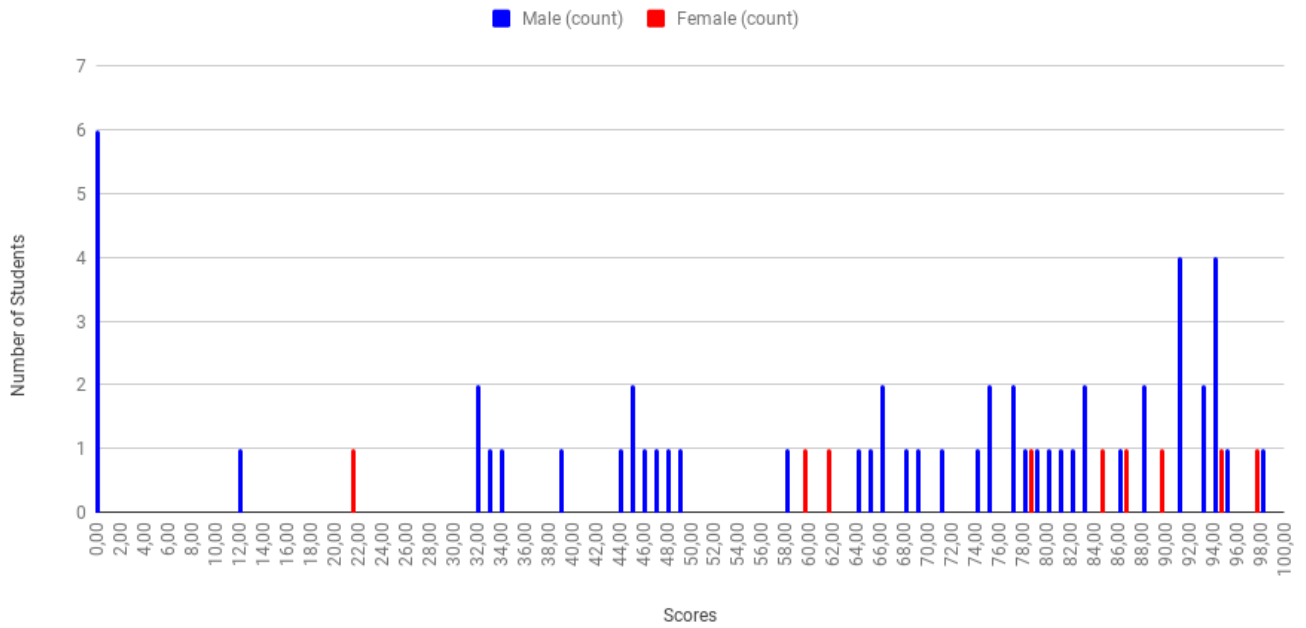
Coursework 1, 2018

Figure 3: *Histogram of the Data Visualization Coursework 1 in 2018 including the average score for males (64) and females (74). Gender is indicated.*
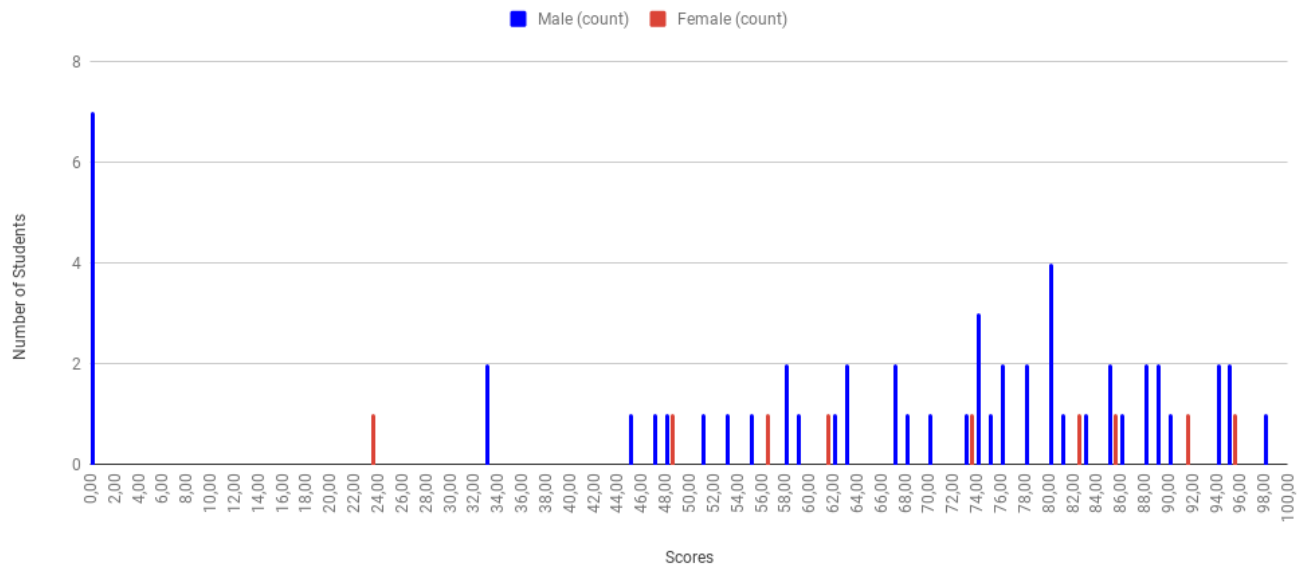
Coursework 2, 2018

Figure 4: *Histogram of the Data Visualization Coursework 2 in 2018 includes the average score for males (63) and females (68). Gender is indicated.*

Similar to higher scores, seven student scores are lower than 20 with four zeros by male students. Much to our surprise, our initial investigation indicates that exam results appear to be evenly distributed between male and female grades from 0 to 86. However, we do notice that a binomial distribution with a dip in the middle with a score of 50. Upon further investigation we noticed a different kind of bias based on language (Asian vs English). This cannot be seen in the histogram but was observed first hand by the teacher.

2018 Information Visualization Assignment

The next two histograms reflect the distribution of the first and second assignment grades. For the information visualization assignment, the females and males perform similarly, and their scores are very close include the average score for males and females. One female and one male student have a score of 98 while six male students receive 0 on the first assignment. Zero indicates that a student does not submit any assignments (See Figures 3, 4).

2018 Scientific Visualization Coursework

Male and female student score better results than on the first assignment. Almost half of the class scores higher than 80 for both genders with some at almost 100% while there are seven 0 scores by male students. None of the graphs for 2018 indicates any gender-related differences.

2013-2017 Exam Results

Furthermore, we create three more histograms over a five-year period for the exam and two coursework for the years 2013-2017 in order to find evidence of gender bias. The histogram for five years' worth of exam results indicates that the distribution of scores is very similar for both genders. Similar to the histograms for 2018, not many female students enrol in our module over these five years. There are 24 females and 148 males enrolled in the Data Visualization module over the 5 years. However, exam results of female and male students show a similar tendency, and they have a similar distribution of exams scores from 2013 to 2017. We observe a peak at a score of 66 with eleven students, and five students receive 0 while only two students receive 98 in five years (See Figure 5).

2013-2017 Coursework Results

In addition, we have two histograms for coursework covering information and scientific visualization over five years (See Figures 6, 7). The histogram representing the first assignment demonstrates remarkable results for 19 students who score 0 and five students scoring 100. Another outcome shows a score of 81 with seven male and one female student. The distribution of male and female student grades in the histogram is very similar to the distribution of the first course-work in 2018. A large subset of the student population performs well since their scores are mainly higher than 50. We also analyse the results of the second assignment over the same period. Compared to the exam and first coursework over a five-year period, the second coursework result is at a higher level, and students receive full marks. Nine males and two females receive the full mark on the scientific visualization assignment while seven male and one female receive 98. Eight male students receive a score of 0. We also observed on the graph that gender bias is not reflected in the grade distribution.

This investigation indicates that scores are generally evenly distributed between male and female students and gender bias is not evident on exams or assignments in histogram graphs for 2018 or over a five-year period from 2017-2013. Although we did not notice any gender bias, we notice cultural bias in our class. From our perspective, overseas students, especially Chinese students, struggle with the understanding the language. In the next sub-section, we provide some recommendations for inclusive teaching.

6. Recommendations for More Inclusive Teaching in Data Visualization

Our Data Visualization course includes two assignments and students are provided data sets to examine in order to produce images. However, some students have difficulties analysing the data set and cannot generate sensible visualizations. One suggestion could be that students should have a chance to select their own data set to analyze and visualize. Students will likely choose data sets that they are interested in and thus perhaps engage more with assignments. Another challenge in the class is language. A language barrier may be present in the class, and many Asian students are limited in their understanding of the lecturer including lecture notes, assignments and exam questions due to a language barrier. This is mainly observed with master level students rather than third-year undergraduate students. The third-year students have time to improve their language skills until their final year at university. A possible recommendation to address this challenge is higher university entry English language requirements. Another approach to address this challenge may be to divide the class based on language skills for the Data Visualization module. The lecturer may adopt a different teaching approach considering students' language diversity. In addition, the lecturer can record the lectures and upload them to an easily accessible web environment such as YouTube. This method enables students to watch the lecture videos multiple times and support them to compensate for not understanding part of lectures. Also, YouTube facilitates subtitles which enable students to follow and understand lecturers.

Our research is concerned with making classrooms more inclusive due to a variety of cultures, student backgrounds and student learning types. Inclusive teaching has many potential benefits such as being collaborative, engaging, and supports the understanding that considers a diverse student body.

Montgomery [Mon01] describes culturally responsive classrooms that consider culturally diverse students. Students need to engage with the subject topic and the tasks that are given them. Instructional approaches and individual teaching attitudes can encourage all students to get involved in learning activities that will lead to improved academic success. Another point described by Montgomery [Mon01] is that the improvement of instructional programs that avoid failure and increase opportunities for achievement should be the goal of every lecturer. Furthermore, Rodriguez-Falcon *et al.* [Rod10] at Sheffield University provide recommendations to adopt a lecturer's teaching approach to meet the needs of a diverse community with inclusive teaching. These suggestions are:

- Lecturers can use clear language and not speak very quickly.
- Handouts and presentations are written and organized clearly. This means a combination of correct color and font size, clear graphs and images. All course material is accessible online.
- The lecturer gives the impression that they are available to answer students' questions and approach them positively for personal engagement.
- Instructors can explain the processes of assessment and feedback. They do not assume students already know the evaluation structure.
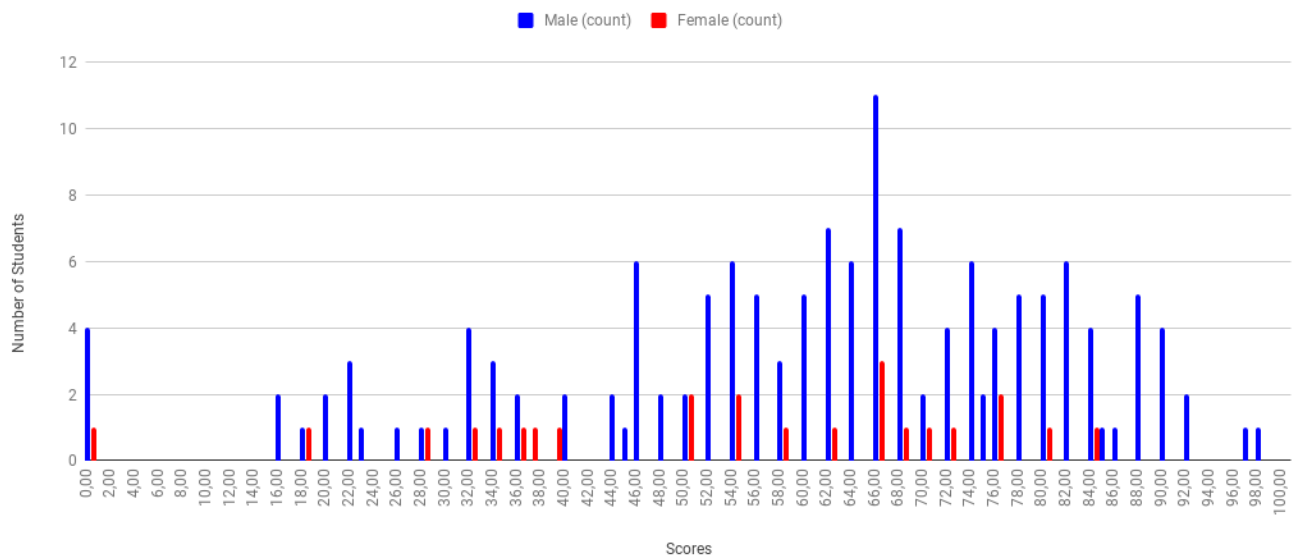- The lecturer chooses common visualization examples for all

Exam, 2013-2017

Figure 5: *Collective histogram of the Data Visualization Exam from 2013-2017 includes the average score for males (60) and females (53). Gender is indicated by color.*
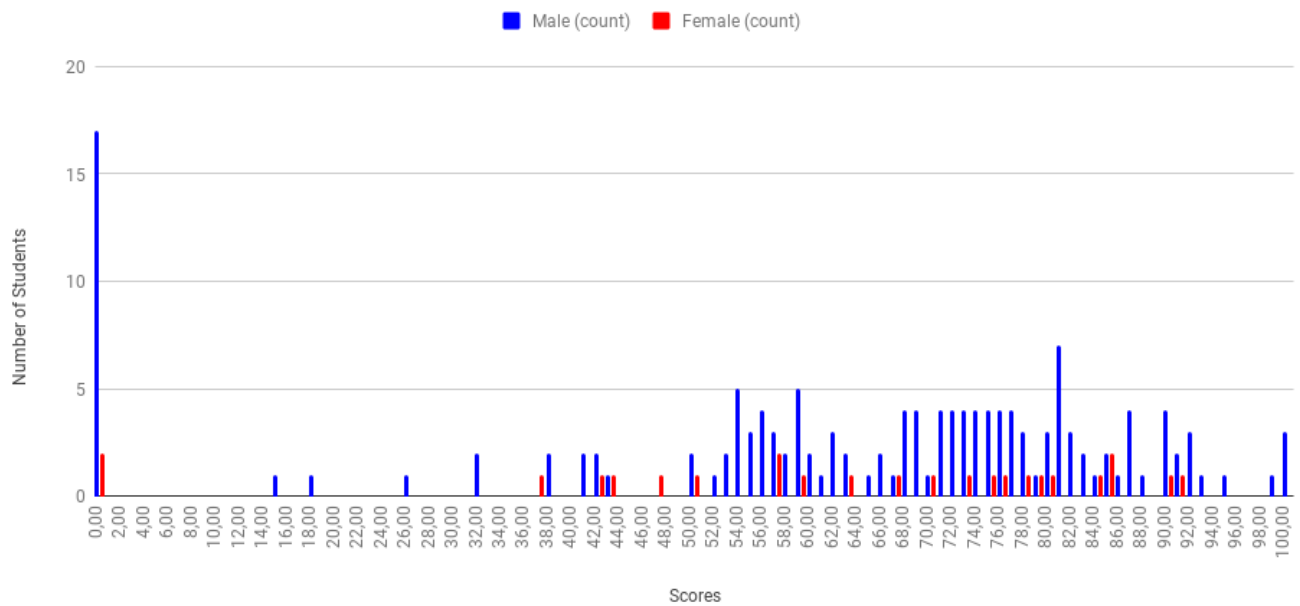
Coursework 1, 2013-2017

Figure 6: *Collective histogram of the Data Visualization Coursework 1 scores from 2013-2017 include the average score for males (61) and females (62). Gender is mapped to color.*

students, especially students who have different cultural backgrounds who can be familiar with the example.

- Instructors can break up visualization lectures to ask questions or include short 'partner-work' sessions.

Other approaches to inclusive teaching for visualization teachers are to support critical and analytic thinking and considering conducting a peer mentoring scheme for assistance for all students.

As a result of this, a diverse community can communicate and assist the learning process for each other in the class environment. Moreover, students should be encouraged to feel comfortable in the classroom and participate in the lecture with their ideas, thoughts and questions. More specific to visualization:

- Those visualization modules that require a visualization project may consider allowing students to propose their own project as
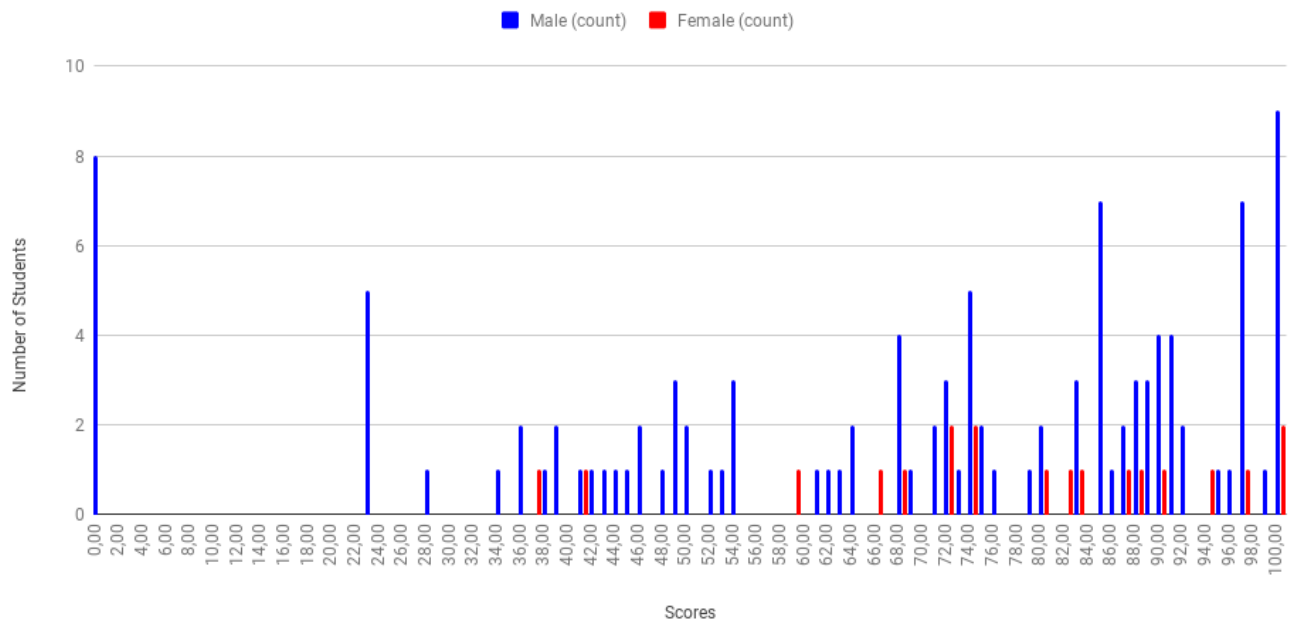
Figure 7: *Collective histogram of the Data Visualization Coursework 2 from 2013-2017 includes the average score for males (67) and females (77). Gender is mapped to color.*

an alternative to a prescribed project. Another option is to allow students to choose between two or more options when selecting visualization assignments or visualization projects. Providing options may support a more diverse student background.

- Data visualization assignments can enable students to generate and collect their own data to visualize rather than using a given data set which students are not familiar to or struggle to analyze.
- We also recommend encouraging the use of diverse hardware including a range of display devices of varying size.
- Another inclusive approach to data visualization class includes the use of low-tech methods such as hand-sketched visual designs life those described by Roberts *et al.* [RHR15].
- And finally, more inclusive teaching can be supported by social media. Social media groups can facilitate convenient and frequent communication between students in a diverse classroom.

7. Acknowledgements

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