Advice From Blind Teachers on How to Teach Statistics to Blind Students

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Abstract

Blind students are bound to make up a very small part of the population most university lecturers will encounter during their careers. Research to date shows that good communication between staff and student improves the chances of a successful outcome for both parties. The research does show, however, that the exercise seems to be one of re-inventing the wheel, perhaps with a less than fully informed blueprint to work from.

The authors use their own experiences as blind students who progressed beyond research methods or first year introductory courses into careers as teachers and researchers of statistical methods to provide guidance for their sighted colleagues. Our principle point of difference to the existing research work is that we rely on the experience of our statistical education for our current livelihoods; we were not one-off students taking a research methodology course or first year introductory course. We benefitted from the successful (and possibly the not so successful) interactions we had with our sighted teachers.

It is our hope that by saving staff from wasted effort, we can spare students from unnecessary discomfort in classes that could improve their future employment prospects. Our aim is therefore to provide practical support for our sighted colleagues and blind peers as we work together towards the empowerment of blind students in becoming competent producers of statistical information, not just consumers who interpret that information.

1. Introduction

The authors are both employed as lecturers in statistics, and just so happen to also both be blind. We feel that our experiences as blind students need to be made more use of so that other blind people have the best chances of successfully studying statistics. These chances will be dramatically increased if their sighted teaching staff are able to tap into the right resources rather than starting with a totally blank piece of paper. The use of the "we" in this article is therefore intentionally meant to be personal in terms of our experiences, but more importantly, also hopes to reflect the needs of the blind community as a whole.

This article is in part a response to a recent article (Marson et al. 2012) of a disappointingly small number on the topic of teaching statistics to blind students. Every resource we found linked the experiences of willing and helpful staff with a single blind student; many of these were cited by Marson et al. (2012), while Cryer (2013) provided a literature review covering a broader range of disciplines.

It is appropriate to first place on record our appreciation of the description of the realities of the learning experience many blind or low vision students will find when they enroll in a university statistics course today, provided by Marson et al. (2012) . More importantly, that article reflects the situation for sighted teachers first faced with the presence of a blind student in their class. Overall, Marson et al. (2012) and the references cited therein present a good summary of the state of things in the late 20th century along with the promise of better things to come in the 21st century. Sadly, some of the projects cited within these references never came to fruition. Even though there is a risk of sounding overly negative, we do provide a reality check in this article; we do not offer hope without promise. The suggestions offered here have proven themselves to the authors whose employment is dependent on them. Every blind student is a unique individual and the suggestions offered in this article may not work as well for them as they have for other blind students.

We feel it necessary to observe that there have been massive changes wrought on the accessibility of university courses in general, and statistics courses are no exception. The authors ask that readers exercise caution when referring to references from too far back in time as the technological landscape is evolving and blind students are heavily affected. As a case in point, it is a very different world for blind students today compared to the very real experiences of studying statistics in the late twentieth century presented by Gibson and Darron (1999). The "braille typewriters, tape recorders, computers, and talking calculators" they described are practically non-existent or have been supplanted by the use of a computer alone. Furthermore, the days of having to receive daily individual tutoring from a graduate student should be behind us. Certainly this level of support will improve the success rate of today's blind students, but they should not be reliant on gaining access to problem questions by having the details read aloud.

It is true that blind people will struggle to learn statistical concepts unless the inherently visual elements are overcome. Marson et al. (2012) do start the interested reader in the right direction, but the most recent developments that may well make the difference between ultimate success and abject failure were not given. We do not intend this to sound critical of the authors; rather, it reflects the inability of the blind community to adequately share the knowledge we do have. All too often it is the blind student that must explain their needs and the limitations they encounter in life. This sounds quite reasonable, but regrettably, blind students are not always aware of the best ways of working; therefore, there is a risk that they will make suboptimal choices about the way they work. With this in mind, it is no surprise that Marson et al. (2012) did not, but more realistically, could not have given the whole story. We therefore offer our thoughts and experiences in order to complement their findings. In so doing, we hope to help teachers of blind students by helping them to provide advice to those blind students that may not be aware of the best tools available today.

In 2007, at the sixth Southern Hemisphere Symposium on Undergraduate Mathematics and Statistics Teaching and Learning, the second author presented some of the solutions he employed as a student. Loots and van Staden (2007) focussed on statistical graphics, but also included a list of additional useful resources. This included screen-reading software, LaTeX, braille translation software, MathML, and optical character recognition for documents with mathematical content. These solutions were only mentioned on a very high level, but they are all still relevant today and therefore warrant further elucidation in this article. Even after the seemingly short eight year gap, there are more vendors and possibilities available currently.

At the 2009 Workshop on E-Inclusion in Mathematics and Sciences, the first author was able to meet other researchers who were also concerned about the low rate of blind people entering the sciences in a broad sense and the mathematical sciences in particular. Godfrey (2009) presented what was then the current state of affairs for blind students taking statistics courses, using his experiences as a blind student and teacher. The four main considerations of Godfrey (2009) were graphics, software, statistical tables, and mathematical formulae. Many of these issues can be resolved if the blind student knows about and then learns how to use the right software tools. They may need support from teaching staff and to some extent will also need to commit extra energy to their statistical studies as compared to the sighted students around them.

In this article, the authors aim to provide a considerably more comprehensive summary of the current state of affairs for teaching blind students than either of Loots and van Staden (2007) and Godfrey (2009), but recognize that making a course truly accessible to blind students will not be easy. For example, the first author supported the teacher of a second year statistics student via email; the solutions described by Erhardt and Shuman (2015) are a pragmatic response to meeting the needs of that student. As discovered by Erhardt and Shuman (2015), the range of tools available could leave most teachers of blind students wondering where to start; contemplating the benefits of some tools undergoing further development compounds this problem.

We feel that teaching and learning go hand in hand and that we must address both sides of this relationship in this article. In order to gain greater insight into the sighted teacher side of the relationship, the authors needed to question their sighted colleagues for recollections of their first impressions (if they taught us) or initial reactions (if they hadn't taught us and didn't know of our existence) when faced with the prospect of teaching a blind student. Some comments from our former teachers have been reproduced in Table 1 for illustration while comments from colleagues who had not taught us appear in Table 2. We have included some brief responses in both tables.

We think there are real differences between the important issues for blind students and what their sighted teachers think are the crucial issues for teaching blind students. In many respects, the classroom is an environment where perhaps those irritating aspects of living in a visual world will be intensified. Blind students are likely to know more about the worries sighted teachers have than do sighted teachers about the needs of blind students. As a consequence, we feel that sighted teachers need to find out what the issues are for the students, which means thinking about the learning side of the teacher-student relationship beyond those initial impressions which are primarily sighted-teacher-centric. Finally, we argue that while blind students will have ideas and experiences about learning in general, they may lack awareness of the best tools that will help them complete a course in statistics or any other mathematical discipline.

After providing descriptions of our own personal circumstances and the legislative environment, we concentrate our discussion on the single greatest concern for the blind student undertaking a modern first course in statistics — the graphical nature of many statistical ideas. We assert that access to information is crucial for the blind person's success in education and future employment. Transferring knowledge about the existence of techniques

Table 1: Comments from former lecturers who are now colleagues. Brief comments from the authors are provided.

Course	Lecturer's comment	Author's response
Intermediate Data Analysis	"I likened many of your issues to assisting an off-campus student on the phone (particularly explaining software). Both parties are largely blind in such a situation."	Yes, thinking of any discussion between a teacher and a blind student as like being on a phone call will help immensely.
Advanced regression	"I often had difficulty translating what I drew on the board into a more digestible form. My approach has always been that a picture is worth a thousand words and I didn't want to abandon that for the rest of the class."	The best descriptions for the blind student are likely to be the ones that are the best for the whole class.
	"When you have prepared PowerPoint it is hard to know how to work through them in a way that works for sighted people but also conveys the same information for someone who cannot see the formulae, etc. I did try to explain in words too but don't think you would have got as much from the lectures as the others."	Yes, lectures may well not have been as useful to me as my sighted classmates, but my ongoing attendance would show that there was value for me.
	"I can't remember any issues at all with assignments or the final exam. If you had questions about the assignments, I seem to remember being able to discuss them with you at least as easily as with anyone else in the class."	Yes, that's roughly how I recall things going. I think it was important for me to be able to have some one-on-one time with my lecturers, perhaps more than did my classmates.
Advanced Time Series	"I tend to rely on visual explanations of statistical concepts — drawing pictures. I think a lot of maths teaching is providing students with dynamic representations of things. For most people this would be visual imagery. If a student has once been able to see, then presumably they will have mental pictures of what things look like. But what about someone who is blind since birth? I can't imagine what maths would be like for them."	Yes, differences do exist among blind students, just as there are differences among sighted students. Some of us will deal with 'visual' content better than do others, and this may depend on any useful vision that we may have had in the past.
Stochastic processes	"To teach a student with a disability would at first thought be additional work but if the student puts in the effort from their side the experience is exactly the opposite — a willingness to put the effort in but not perceive it as extra effort."	Yes, a student who is blind often has to put in much more effort than fellow class mates, however, this usually leads to such a student performing just as well, or even better, than others. If a lecturer had to make some alterations in the way a course is commonly presented, they too may benefit from these, for example, using technology optimally.

Table 2: Comments from colleagues who are not former lecturers. Brief comments from the authors are provided.

Colleague identifier	Comment	Author's response
Mathematics tutor 1	"My immediate reaction would be one of slight confusion and panic. I would be thinking of all the visual material I rely on when I lecture and wondering how good my verbal explanations that go with my vast amounts of whiteboard notes actually are."	These comments reflect the attitude common among the vast majority of the teachers I encountered in mathematics and statistics courses. The concern needs to be kept at the level of improvement rather than becoming debilitating though.
	"I would like to know how the blind student will take notes in lectures, and if they have software available to be able to read material that is on" our online teaching system.	Valid concerns that aside from reading any mathematical formula are not specific to courses in mathematics or statistics.
	"I would presume they would have a reader/writer available to them for tests and the exam, but this is not always desirable as the reader writer does not necessarily have any understanding of the material."	All too true. Careful selection of the right reader/writer can make huge differences, and my preference was to use a graduate student wherever possible.
	"I know there would be many things that I would also think about during the semester and would hope that I had a good rapport with the student so that we would feel comfortable discussing any issues as they arose."	Good approach. We can't ask for much more than that.

into actually being able to perform them is required if blind students are to gain employment. A dominating feature of this article is therefore the distinction between a person being a consumer versus a producer of information. With this in mind, successful blind students of statistics must know what each graphical device intends to portray in theory, how it is constructed, and what it actually portrays with respect to a particular data set being used in practice. This is of course no different to what is expected of their sighted classmates and is a feature of most introductory statistics courses. In addition to this, the modern statistics course also usually incorporates practical engagement with data and necessitates use of statistical software to create these graphical displays. After considering the range of media that could help bridge the visual divide, we turn to the wide range of other concerns we have about the statistical interactions blind students will have with the sighted world in which they live. We contend that the learning outcomes for a blind student must and can be the same as those for any other student taking statistics courses.

2. Levels of Blindness

The word ‘blind’ is used in this article in the widest possible sense. Many people who are comfortable using the word ‘blind’ to describe their vision do have some residual vision. As a case in point, the first author does have some residual vision which might help with personal orientation in the physical world, but is no use in the classroom or for handling any information such as textbooks and other printed material, or for using a computer. During his undergraduate days, he could use a closed circuit television (standard magnification technology) for reading and writing some material, but in many situations access to information using visual media was not reliable. The technology available during the 1990s did not facilitate much independent access to information, so he was completely reliant on humans for reading all printed material, and in some cases, to assist with completion of assignments using statistical software. Usefulness of the closed circuit television technology ceased at about the same time as he moved from undergraduate to postgraduate level mainly because his condition is degenerative. This is not the place to justify or question the fact that he did not learn any braille code until he had already completed his PhD. As a consequence, though, braille is not his preferred medium but is used to support his work by way of a braille display connected to his computers. In addition, he has access to braille embossing equipment to produce hardcopy braille and tactile images.

In contrast, the second author used a closed circuit television up to midway through his undergraduate studies and then made the transition to braille. Although he was familiar with the basics of the braille alphabet, he only picked up braille mathematics at that time. Braille literacy, however, does not guarantee independent access to study material nor to communication in a sighted world, i.e. completion of assignments or examinations. Both authors wholeheartedly support the use of braille, but like many blind students of today, we were not competent braille users when we started university.

In both cases, knowledge of the authors’ medical condition is somewhat irrelevant for the discussion at hand. Disclosure of our conditions poses no problem for either of us, but we understand that not all blind students will want to share such details as readily as either of us might; in some cases students may have the right (protected by law) to non-disclosure. There is also a danger in assuming all people with the same medical condition will have the same outcomes in terms of how they live with their level of vision and how the problems that present themselves in life will be tackled. We would advise teachers not to initiate conversations about what a student can and cannot see until they know that their student is comfortable having this discussion. As an alternative, it may prove quite useful for teaching staff to understand both how a blind student will work and what equipment and resources they have access to at home and on campus. A discussion centering on these practical aspects will almost certainly avoid any discomfort the student may have about his or her medical condition and start to build the rapport that will improve the chances of a successful course completion.

3. Legal Landscape

The range of legal frameworks that guide or direct the way any disabled students will be treated by universities is too vast to consider in this article. It is certainly true that in some jurisdictions, the obligation for providing all manner of resources to students lies heavily on the university by way of the teaching staff or a Disability Support Service of some description. In other jurisdictions, the legal framework is present but is less well understood or even non-existent.

Both authors work at the universities where they undertook all of their university education. The legal framework of both their countries states that a blind student should be accommodated so that they have the same opportunities as any other student, but there is no explicit statement in the relevant legislation that says how these accommodations will be made, or by whom, let alone what constitutes a ‘reasonable accommodation.’

Even if the legislative framework is not strong, the authors feel that there is at least a moral obligation to assist any student enrolling in a course, even if that student is blind. The authors also feel very strongly that the legislative obligations placed on teaching staff at universities should not over-compensate to the point of providing unnecessary advantages for the blind student. It is entirely reasonable in our opinion to expect a university to provide information to a blind student in a readable format, but this stance cuts both ways; a blind student should be able to present their work in a form readable by the intended audience.

In some jurisdictions, a blind student is able to prepare their assignments in braille that is then translated by another person into readable text for marking. While this may be an acceptable method of working while a student is at primary or secondary school, it is not viable in the real world of employment. At some point the blind student must wean themselves off using human resources for translation from their chosen medium to a form readable by their colleagues. We feel that the time for this maturation is during the blind student’s university education, if not done prior to it.

The extent to which blind students rely on the support services available to them at their chosen universities will be dependent on their reasons for taking a course in statistics, their intention to complete other courses reliant on the skill set learned in the statistics course, and their career aspirations to name just a few considerations. These are, of course, the same set of considerations that would be evaluated for sighted students undertaking the same courses.

The authors contend that blind students should complete statistics courses with the same educational outcomes as any other student, although the means by which they achieve these ends will almost certainly differ. The unanswerable question is this: “What sort of expectation can teaching staff assume is fair to place on a blind student, and what sort of ‘reasonable accommodations’ form the obligation on the teaching staff?”

What constitutes a reasonable accommodation? The authors believe that making allowances for some activities specific to a university course makes sense. For example, tests and examinations are activities undertaken in educational settings, but rarely in the workplace. Universities should therefore take all manner of steps that ensure a blind student can undertake tests and examinations using a sighted assistant and the technological aids they have that will maximize their ability to show what they have learned. On the other hand, it is highly desirable that a blind student can create graphical or numerical summaries of data without reliance on sighted assistance if this is a skill expected of all students.

The authors believe it is improper to suggest a ‘one size fits all’ solution in this article. The personal circumstances of blind students, legislative and moral obligations of university staff, and the availability of university-level support services all play a role in determining the ways blind students will complete courses in statistics. Ongoing dialogue among all relevant parties will surely make the learning of statistics by blind students a more meaningful and engaging experience for students and teachers alike.

4. Teaching Graphics to Blind Students

4.1 Describing Graphs to Blind Students

Perhaps the best starting point is the question, “How should I describe a graph?” The answer is simple but not helpful — “it depends.” There are a variety of ways to approach converting any picture into words. The most concise would be to use the figure’s caption or to create one to summarize the content of the picture. The other extreme is to explain every detail included in the graph so that in effect the graph could be reproduced from its description. Ultimately, the context must determine the amount of time spent describing the content. For example, the first time a scatter plot is mentioned in an introductory course, it is reasonable to expect a fairly detailed description which will benefit the whole class. It is also reasonable to expect that descriptions of the specific details about axis labels and units of measure might start to detract from the flow of the presentation. At times, the choice to use a graph is an exercise in cosmetics rather than a necessity because of the way the presenter is talking their audience through the material.

The authors advise sighted statistics teachers to act as statisticians when thinking about graphs. Behind every graph that has been created lies an intention to pass information, not usually data; it is this intention that should be communicated in the description. For example, in the section of a text that introduces scatter plots it would be preferable to provide a full description; the same dataset might also feature in the material talking about linear regression where only the linearity of the data is relevant.

There are many resources that explain the way a description should be developed. A set of guidelines (available at http://www.ukaaf.org/guidance-downloads) have been developed by the UK Association for Accessible Formats. They extend the points raised above to a general audience. Of particular note, the question of who should create these descriptions is explicitly mentioned in UK Association for Accessible Formats (2012*a*); it notes that the author of the content is the person in the best position to judge the value of the description. This is a crucial point to note with respect to scientific content in general and statistical graphs in particular because many descriptions are created by transcribers who do not have the right knowledge to ensure that their subjectivity does not interfere with the blind student's ability to digest the material. The guidance on offer is limited to a small number of graph types and does not currently include such basic statistical tools as histograms or boxplots. It is clear from the examples how a description is formulated to give insight into how the interested teacher would approach descriptions of image types not explicitly covered. For example, the template has a graph with the following description:

> "This scatter graph is titled Growth of three insect species and shows how their growth changes over time. The x / horizontal axis are labelled 'Age (days)' and are marked in days from 0.0 at the origin to 25 days, at intervals of 5 days. The y / vertical axis is labelled 'Size (mm)' and is marked from 0.0 at the origin to 3.0, at intervals of 0.5mm. The points show that all insects increase gradually in size. The general trend shows that insect A grows the largest; insect C is the smallest, with insect B in-between. The general trend is upwards. The width of the scatter widens as the insects grow, showing more variation in size as the insects grow. There are many points marked, so the data is hard to read accurately. " (UK Association for Accessible Formats 2012*b*)

This description is quite comprehensive, and even the sighted reader of this article should have been able to visualize the graph being described. Some minor details have been omitted from the description (such as the type of symbol being used), but such details are often less relevant than those provided. A more statistically inclined description would offer more in terms of the nature of the upward trend and include use of words like 'linear' or 'curved,' etc., that would provide more information than is offered.

The specific guidelines for describing charts and graphs presented in UK Association for

Accessible Formats (2012*b*) are relevant across a wide range of disciplines where the intended audience consists of consumers of the information presented in the image. In most statistics courses, however, there is an emphasis on *producing* statistical graphs. The examples given in UK Association for Accessible Formats (2012*b*) would show blind students what they would be expected to be able to convey to their sighted audiences if they are to be a producer of knowledge via these visual media. The fullest descriptions offer some insight into the ways blind students might uncover the information for themselves without reliance on the image.

4.2 Using Tactile Images to Represent 2D Constructs

We need to address the (often misconceived) notion that blind people can learn through touching two or three dimensional representations of visual concepts. Knowing how to read a tactile image properly is not a skill we are born with — it needs to be learned. The value of the tactile representation will be very dependent on the blind person's potential, just as sighted people have differing abilities to learn kinaesthetically. The ability of a blind person to read a tactile image is also very dependent on the quality of the image being created and is therefore open to an extra layer of interpretation as the printed picture is converted by a subjective human process into a tactile image.

Some fairly inventive ideas have been put forward for creation of tactile images/objects over the years. For example, Gibson and Darron (1999) mentioned the use of a clay model to depict the normal distribution. There is no reason to go to this extent in the current era. Tactile images can be made available by use of braille embossers, swell paper, and 3d-printing.

There are a number of ways to generate two-dimensional tactile images in common use today. The simplest option from a producer's point of view is probably the use of swell paper (see http://americanthermoform.com/ for one source for equipment and advice). This special paper has millions of heat sensitive cells that expand like popcorn when heated. Marks can be added to the swell paper using a standard photocopier or a marker pen. Once the page has been marked, it gets 'cooked,' and the final tactile image is ready for the blind person. This image is quite durable, and the initial cost for the cooker is quite reasonable. The cost per page is, however, quite high compared to regular paper (sheets can cost as much as US$4). The results are quite variable and to some extent are very dependent on the original graphic being represented. Technologies such as this might produce an interpretable graphic, but superior options do exist nowadays.

Many braille embossers can render graphics onto paper. As an example, the products of ViewPlus Technologies Inc. (see http://www.viewplus.com) are designed to produce higher quality tactile images and are well worth being tested by blind students and their support networks. The first author has printed graphics straight from an R (R Core Team 2014) graphics window to a Tiger Embosser while the second author has demonstrated the value of this approach (Loots and van Staden 2007) using SAS (SAS Institute Inc. 2010).

The best embossed statistical graphs will use the maximum width possible on the paper. This will help blind readers avoid getting tangled up in the clutter and gives them the greatest chance of understanding the structure and the intention of the graph. In this respect, statistical thinking can be linked to tactile graph perception.

The use of embossed images in place of swell paper solutions is a matter of personal preference. The cost and simplicity of swell paper has held an advantage for a number of years, but the cost of braille embossers is coming down. At US$2000, the latest ViewPlus embosser is now within reach of most tertiary institutions and high schools catering for blind students. Braille embossers do use heavier (135-160GSM) paper than normal photocopier paper (80GSM), but this cost is trivial compared to sheets of swell paper. This extra financial cost must be weighed against the immediacy that an embosser offers.

A blind student with direct access to an embosser could analyse univariate and bivariate statistical graphs in little more time than would a sighted student having to work using a standard printer. Until such time as technology for the blind is developed that replaces the computer monitor, creating an embossed image is the best solution available. If we can produce a tactile representation of the graphs needed for sharing with a sighted audience, and if we can therefore be confident that the result is what the sighted audience is expecting, then we can produce statistical graphs just like our sighted peers. We can do this by embossing the graphs used in classroom examples as well as those used for assignment work and other data analyses.

One last solution receiving attention of late is the creation of objects using a 3d printer. The ability to take an image with layers (explicit or implicit) of detail to create a three-dimensional object that uses a different height for each layer looks very promising. For example, the standard diagram showing the empirical rules for a normal distribution needs an axis with integers from –3 to 3 marked, the curve for the normal probability density function, vertical lines joining each integer value on the axis to the normal curve, and the details about the proportion of data that are expected to lie within each zone. The horizontal and vertical lines are needed but are only guides; thus, they should be at a low height. In contrast, the most important details of the normal curve's shape and the lines marking the three zones of interest should be 3d-printed at a greater height for emphasis.

4.3 Using Tactile Images to Represent 3D Constructs

We cannot dismiss the usefulness of the wonderful results that can be gained through hand-made two and three dimensional tactile objects entirely, but these objects can only teach concepts from a theoretical standpoint; they do not and cannot be used for exposing blind students to the realities of data analysis.

For example, depiction of a bivariate scatter plot is relatively simple using a two-dimensional tactile image of some sort. Presentation of three-dimensional data is near to impossible as the pictures used for sighted students rely on an understanding of depth perception. For some blind people, spatial awareness is an issue; that is, their awareness of their surroundings and how it all fits together is actually quite limited.

Even the advent of 3d printers cannot fully counteract this lack of perspective. A blind person holding a cube doesn't necessarily understand the fact that a sighted person cannot see the back side of the cube because the blind person is experiencing the cube as a three-dimensional object. Handling the cube on its own only develops three-dimensional thinking.

4.4 Issues to Consider When Assessing Blind Students' Understanding of Graphics

A modern statistics course demands that assessment includes interpretation of graphs. The authors contend that if blind students cannot learn how to create these graphs for themselves, then, they cannot prepare themselves for an examination or test on this task to the same extent as their sighted peers.

Educators also need to ask themselves if examination or test questions actually test the task or the understanding gained from creation of the graphs. Often this is done by asking a student to interpret a graph, but if that graph's interpretation relies on the student's ability to interpret an inherently visual idea (as against a statistical notion), then teachers should re-assess the validity of the question. We know that a person's perspective depends on a number of aspects, which might include gender for example. If there are situations where it is unfair to use a particular type of question because it favors some students over others, then the same question can be reasonably asked about blind versus sighted students.

As a first case in point, consider questions about a boxplot in an examination context. These could be aimed at the ability of a student to extract the median and quartiles from a sample, evaluate the extreme points for outlier status, and then construct a hand-drawn graphic; or, the graphic could be printed in the examination and questions about the content of the graph and the data it portrays could be asked. A blind student undertaking this examination would be able to direct the reader/writer in how to create a boxplot once they have found the relevant five-number summary and determined outlier status for the extrema. The person drawing this graph on his or her behalf would not be as influential in the successful completion of this task as compared to someone reading from an existing boxplot. Even though the idea of manually constructing a simple graph like this would seem very old-school to some, the presentation of graphs in an examination and asking for an interpretation primarily examines a student's ability to consume statistical information delivered visually.

Now, consider as a second case in point the description offered for a scatter plot in a publication mentioned earlier in this article (UK Association for Accessible Formats 2012*b*). In particular, the two sentences "The general trend is upwards. The width of the scatter widens as the insects grow, showing more variation in size as the insects grow" are so descriptive that they may well act as the answer to an examination question. The only way to ascertain if the student understands that these features are important to look for is to leave them out of the description and wait for the student to ask what sort of trend is present, and if the points show constant variance. Opportunities for this sort of interactivity are not normal. It is more common to see examination questions that ask for a description which would leave the blind student at the mercy of the reader/writer assigned to them or the quality of any tactile images produced. A question that states the presence of the non-constant variance and asks the student what they should be worried about in such circumstances treats all students equally.

The balancing of producing and then consuming statistical information will surely shift as statistics courses develop in the coming years. At that time we will be more concerned with the medium used for the assessment more than the content of that assessment. We will continue to ask if the method and content of assessment is fair to all students. We believe that if assessment tasks are designed to truly test statistical understanding instead of visual interpretation, and if a student can make use of appropriate tools, a blind student can successfully demonstrate his or her knowledge just like any other student.

5. Other Considerations for Blind Students Studying Statistics

We have discussed issues in producing and consuming statistical knowledge via graphs. The problems of dealing with statistical graphs is a solved problem (in theory anyway), but the way things happen in the classroom is lagging well behind. The challenge for the blind student is to be more than just a consumer of the knowledge gained from statistical graphs; we (the authors) know that we (blind people in general) can produce statistical knowledge if we have access to appropriate specialist hardware and the right software.

While the issues pertaining to graphs and ideas taught using them may be top-of-mind for sighted teachers, they are probably much less of a concern to blind students. We now turn our attention to the more worrisome issues for blind students studying statistics in the modern era; not all of which are resolved to a satisfactory standard.

5.1 Access to Reference Material

Being able to use the same resources as their classmates is perhaps the greatest burden on blind students. A very small proportion of reference works are converted to any format that can be independently used by a blind student. This is especially true in the sciences. One common problem is that a text may not be converted at all or only a previous edition is available. The burden for each blind student is finding out what texts are required so that there is sufficient time available to get a copy ready in the format of his or her choice, whether that is in braille or an audio recording.

With many courses now relying on web-based content, the accessibility of the content every teacher makes available to their students needs to be given explicit mention here. It is all too common for documents to be converted to the portable document format (pdf). This document format does have its benefits, but the vast majority of these documents will not be fully accessible to the blind students relying on specialist screen reading software to read them. Every document made available to a class in pdf will need to be made available to the blind student in its original format. See some additional comments on other file types in Table 3.

There are two types of pdf documents that need to be discussed in more detail. The pdf that was generated by scanning a printed page can only ever be read after processing by an optical character recognition (OCR) application. There will be imperfections with the result of this process, so it is often worth our effort to find an original source or alternative resource that is more accessible to us. Software does exist for this, but post-processing by a human is required to ensure the final document given to the blind student is accurate. See more about the most advanced software (Infty Reader) in this area at http://www.inftyproject.org/en/index.html.

The second set of pdf files common in mathematical disciplines are those authored using the LaTeX system (Lamport 1994). The main value of LaTeX documents is that the formatting for presentation is kept separate from the content. The raw input files are plain text and are therefore readable by blind people, but the mixture of content and formatting commands can make it a little confusing for the novice LaTeX user. Two problems present themselves with these documents; neither the ligatures (pairs or triples of characters joined together to form a single printed character such as ‘ff,’ ‘ft,’ and ‘fi’) in the regular text or

Table 3: Strengths and weaknesses of various types of electronic files.

Type/Extension	Good for...	Bad aspects...
Adobe pdf	Nothing	Many different types of pdf (some of which are completely unreadable); No mathematical content is readable; difficult to deal with even when just regular text.
Microsoft Word doc/docx	General accessibility is high; common so screen readers deal with these adequately in many situations.	Standard equation editor output is not readable by screen readers.
Microsoft PowerPoint ppt/pptx	On-going development of screen reading software should in theory provide some access to textual content, and eventually mathematical content created using MathType	Spatial oriented material could be challenging to navigate; hard to find information.
Microsoft Excel xls/xlsx	Great for data manipulation, and small computations.	Generated reports may be difficult to navigate. Other tools are better suited for statistical processing.
Epub	Great alternative to pdf files. Can render mathematical content using MathML, which can be accessed by screen reading software.	Limited uptake for classroom use.

any of the mathematical expressions that make using LaTeX worthwhile are read aloud by screen readers. We can get used to listening to a document that doesn't read the ligatures and still get the gist of it, but there are ways of avoiding the creation of the ligatures (e.g., adding a suitable package to the source LaTeX file's preamble where global adjustment for formatting is done). Accessing the mathematical content in a pdf is a major problem. OCR software for processing a pdf containing mathematical content is currently a work in progress. We are often forced to read the raw LaTeX code that created these documents in order to gain absolute certainty of their content.

5.2 Braille Concerns

Even though the nomenclature of mathematics is universal, its braille equivalent is not. It is true that many blind children will have learned one code for representing mathematics in braille, but this depends on where in the world they gained their blindness skills. The blind mathematics lecturer Abraham Nemeth (1918–2013) created the Nemeth code for his own use so he could deliver lectures; he is reported to have kept his notes on cards in his pocket, reading the braille with one hand while writing on the blackboard with the other.

Unfortunately, many blind university students will not have learned enough braille to survive, let alone a mathematical braille code. Many documents that include mathematical content use the Nemeth code because they were created in the United States. For this reason, the authors' believe that any blind student living in the majority of countries not currently using Nemeth will need to seriously consider learning it if they intend to continue studying any mathematical discipline to a higher level. It is unreasonable, however, to expect a student to pick up a new braille code such as Nemeth for a single course of study.

Even in the United States, the use of the Nemeth code is in question. The braille Authority of North America has determined that this code will only be used for technical material, while the Unified English braille Code (UEB) will be used for other texts. UEB has now been adopted by the majority of English-speaking countries for general use.

The tools that convert mathematical content into braille must cater to the plethora of braille systems. Most current systems (including the Nemeth code) have their limitations for backwards and forwards translation into any human readable mathematics representation. The decision to promote UEB in preference to Nemeth is largely based on the view that it is too difficult to reliably convert Nemeth into regular print for the sighted world. Ultimately, it is the use of a standard such as MathML (World Wide Web Consortium 2014) that will ensure that those people using a less-common code will be able to read the MathML representation somehow. To quote the aforementioned standard, "MathML is a markup language for describing mathematical notation and capturing both its structure and content. The goal of MathML is to enable mathematics to be served, received, and processed on the World Wide Web, just as HTML has enabled this functionality for text. … While MathML is human-readable, authors typically will use equation editors, conversion programs, and other specialized software tools to generate MathML" (World Wide Web Consortium 2014).

5.3 Authoring Mathematical Content

Until such time as there is a reliable translation tool that will convert mathematical braille systems to and from LaTeX or any other form of authoring mathematics, all blind students taking any course involving any mathematical notation will employ a system specific to them. It is up to the student to find a solution for making his or her work readable by the sighted world, both as students and later in their future working lives. How any blind student will gain access to the printed word (especially if it includes any mathematical content) remains a largely unresolved problem. Each student will have his or her own skills, strengths, and weaknesses. Some will use synthesized speech, but for others, this is not an appropriate medium for dealing with unfamiliar mathematical content.

For many years, blind people have relied on human support to help get their personal notes converted into a format that is readable by their sighted teachers. Expressing mathematical content is fraught with difficulty as many expressions can become ambiguous if the reader does not fully identify the mathematical structure correctly. The aforementioned Abraham Nemeth created a system known as MathSpeak which was intended to remove ambiguity. As an example, how often do we hear teachers say “x minus mu over sigma” when they actually mean to convey “x minus mu all over sigma”. This distinction might not be so important when the audience can see the expression as a fraction, or the brackets surrounding the numerator component, but the sighted students in the classroom wouldn’t lose anything by the addition of just one word that offers a great deal of clarity for the blind student.

It should seem obvious from the above discussion that blind students intending to undertake more courses in any discipline featuring mathematical content will need (at least) a rudimentary understanding of LaTeX. Even if they do not wish to produce full documents using LaTeX, they will need to gain access to the mathematical symbols and fonts via tools such as MathType (Design ScienceInc. 2010) using LaTeX, because the point and click tools offered in word processing software are not accessible. Use of MathType in conjunction with Microsoft Word means that we can “toggle” to/from the LaTeX representation of every MathType object in such documents. Entering the mathematical content required for the normal introductory statistics course is a reasonable expectation to have of all students nowadays; blind students will just need to know the corresponding LaTeX code.

Both authors have a level of comfort with LaTeX for document preparation, and the first author is also using markdown documents which incorporate use of LaTeX to generate equations. Manipulating mathematical expressions using raw LaTeX code in any of the document preparation systems mentioned is far from easy. The LEAN authoring system (Gardner 2014) builds on the content created with MathType by using real words in place of the symbols and Greek letters found in many mathematical expressions. One of its best features is the ability to add these text descriptions to every MathType object in a Word document to make it considerably easier to read. In addition to offering the user menus for literally thousands of symbols and operators, LEAN also includes functionality for some simple mathematical manipulations.

5.4 Performing Calculations

One major issue for the blind student of any mathematical discipline is how to adequately replace the pen and paper notepad for manual calculations. Historically, these calculations could be made on a manual braille typewriter and then transferred to a document fit for the sighted world. In our working lives, we will be able to use all manner of tools that work for us such as LaTeX and related tools (as mentioned previously), statistical software, scientific calculators, and the like. These tools circumvent the need to access such relics of 20th century statistical work as paper-based distribution tables. Sighted students are now often using scientific calculators with very sophisticated functionality. It is very pleasing to see the development of talking scientific calculators such as the Orion TI-84 Plus, which puts blind and sighted students back on an even footing. Its advertising says, “Explore graphs using either spoken announcements or innovative “sonograph” audio and haptic (vibrating) feedback”. This could prove very useful for describing distribution functions for example. Neither author has yet tested this particular model because it would prove to be little more than an expensive experiment. If a class were using the corresponding standard model, then we would wholeheartedly support a blind student obtaining and testing the T-84+. Other (cheaper) solutions exist for the authors and therefore all blind students.

For those blind students unable to obtain a talking scientific calculator, the solution might be to have them use suitable statistical software instead. This could of course prove difficult for examinations and the like, but the solution is only a discussion away. Use of a free software tool such as R in place of a considerably more expensive scientific calculator or difficult to use statistical tables might be considered. Limitations on the use of the substituting software could well be appropriate.

5.5 Statistical Software

Teaching any student how a task is done and what it should deliver in terms of knowledge teaches that student to be a consumer of statistical analyses. There are many reasons developers of curricula want students to know how to create and interpret data so that they can become producers of statistical analyses. Just as we expect sighted students to take data they may have collected themselves and make appropriate graphs that are then interpreted, we should expect our blind students to do the same tasks. The challenge is to work out how we can meet these aspirations. We contend that much work is yet to be done in this regard, but we need immediate solutions that are practical in real time.

All students need to create and interpret simple graphical and numerical summaries for their data. Blind students are no different, but we need to know what software we can actually use. Readers wanting to know more about accessibility of statistical software should look at the most current knowledge via http://r-resources.massey.ac.nz/statsoftware/ or a static commentary given by Godfrey and Loots (2014).

The authors use R and SAS as their preferred statistical software. These are not commonly used options for introductory statistics courses, but many other more commonly used applications are not feasible or practical options for the blind student. For example, Minitab (Minitab Inc. 2012) uses dialogue boxes that are difficult for screen reader users, and SPSS (SPSS Inc. 2012) is only useful for users of the JAWS (Freedom Scientific 2012) screen reader (Godfrey and Loots 2014). If the student intends to take a single course in statistics so that he or she can become a consumer of statistical knowledge then the most practical solution is to provide the necessary human support to drive the software on his or her behalf to successfully complete the course. If, on the other hand, the blind student has any aspirations of becoming a producer of statistical knowledge in any discipline, then he or she may have to invest some time into learning different software to that being used by sighted students.

6. What the Blind Student Must Do to Prepare

In our discussion we have identified a number of additional tools that blind students will need if they really wish to reach their potential in a statistics course alongside their sighted peers. Some of these solutions will take time and energy; learning the additional skills while trying to learn the same things as their classmates could well prove too much for many blind students. We believe, therefore, that it is crucial that blind students adequately prepare themselves for taking on the challenge that a statistics course will entail. Time should be committed before the semester starts, especially if new software is to be learned, for example.

Many students take an introductory statistics course to support their studies in a wide range of other non-mathematical disciplines. The same is likely for blind students who historically have preferred qualitative subjects because there are considerably fewer barriers to overcome. These students (blind and sighted alike) are generally less well-prepared for an introductory course in statistics than the more mathematically inclined. The very real problem is that the concerns for the sighted students in this situation are easily overcome, especially as they are surrounded by other students experiencing the same problems; the blind student will have these problems and more to contend with, and (blind) peer-to-peer support will not be so readily at hand.

There are various networks that blind students and their support staff can make use of. The 'blindmath' email list (hosted by the National Federation of the Blind) is one such network. As many topics that are of concern to blind students crop up year after year, the list's archive is a good starting point for anyone wanting to find out about the personal experiences of blind people using the tools described here.

7. What the Teacher Can Do to Prepare

Much of the literature about teaching blind students focuses on what these students cannot do; in contrast, we support the view of Andreou and Kotsis (2005) and argue that there are a number of tasks and concepts where blind students will have advantages over their sighted peers. For example, the first author offers the following reflections:

- I found working in more than three dimensional spaces easier than many of my classmates who wanted or needed to see a representation of the ideas being discussed.
- By not being able to see the detail of some working, I had to remember the principles being used so that I could work through examples after class. I think this means I rose to a higher level of understanding.

The second author adds:

- Although an intuition for statistical concepts is initially fed through visual representations, I found more advanced topics, like dealing with matrices of non-real valued variables, to be a natural step forward.
- Since I captured most of my work electronically, I always had back-ups and could provide my supervisors with on-going drafts. This greatly eliminated the dreadful write-up portion of a dissertation, including wasted hours on formatting and numbering.

Both authors monitor an email list where a current student noted, “In various economics and statistics classes that I have taken, when the professor has done well to read the board and describe key graphical concepts, I have left the room understanding the material better than many of the other students in the class. I haven’t used tutors, but sitting down with classmates to work through problem sets has been when I really felt that I was gaining a firm handle on the content.” In a personal communication for clarification, he stated, “To be clear, I do not dispute that I am at somewhat of a disadvantage in not being able to read the board/power points. It can be harder to grasp formulas and graphs. But if the instructor makes even a moderate effort to communicate the essentials, I do ok. But I certainly have sat through lectures and wondered why I bothered attending.” (Waylon 2015).

If the authors were teaching other blind people statistical ideas, we would be able to call on the experiences we have as blind people. Teaching blind people about randomness, probability, and distributions is possibly an easier task than it is for sighted students because these are concepts we live with every day. Vision gives sighted people a degree of accuracy and precision that blind people do not possess; we guess a lot! We employ strategies in life that rely on probability although perhaps we never used the term to express what it is we do. When blind people reach for a door handle, they may use their experiential knowledge to pick if the handle is horizontal or vertical and adjust the position of their hands accordingly; they might have their fingers spread wider apart to cover the lack of confidence they have about the exact location of the handle — some would say we are inherently Bayesian, but

Table 4: Suggestions for teachers of blind students.

Good ideas	
Issue	Comments
Provision of material	Conversion to alternative formats such as braille or audio recordings takes time. Providing as much material as possible well in advance of the classes or times when they are needed will help the blind student plan ahead.
Checking accessibility of software	This is best done prior to semester commencing. If the course staff cannot assist the blind student in installing and testing some software, then finding the right support staff to do this will prove very useful.
Traps to avoid	
Issue	Comments
Language	The words "here," "there," "this," and "that" require a visual gesture to be interpreted. Even the sighted students in the class will benefit from the elimination of these words from lectures as they cannot listen to you and write notes simultaneously.
Refusal to provide notes	If you write onto a board from your own notes, you need to provide the blind student with a reliable copy of these notes. Assuming a student can obtain a true copy from his or her classmates is an unfair burden to put onto blind students or their classmates. Everyone who takes notes has a particular style. Finding a match for the style of the blind student's needs will be problematic, so it is much better to provide the original material.

the reality is that perhaps we appreciate there is a distribution of possible outcomes for more scenarios in life than tossing coins or rolling dice.

The question is, "Can a sighted person dream up the scenarios that are material to a blind student?" The answer is surely, "Yes!" A great skill for any teacher is the ability to reach out to their students by asking questions and creating examples using topics that matter to them. Teaching a blind student will have its challenges, but this is an opportunity for staff to improve their teaching skills in a way that will benefit all students. We suggest that the proactive teacher of a blind student will want to take special note of the best and worst practices we have encountered, as described in Table 4, which are for the most part applicable to teaching any subject.

In Table 5 we have identified several areas of software development where there is likely to be the greatest development between the time of writing and the enrollment of a blind student. We recommend that teachers obtain the latest information on these topics as and when required.

Table 5: Some topics where investigation of the current status is required.

Issue	Comments
Reading/writing mathematical expressions	At the time of writing, no software provides perfect rendering of mathematical expressions in such a way that a blind author can be confident that the result is what was intended. The LEAN authoring tool is the closest to providing such a solution that can meet the widest set of needs; it is under ongoing development. Notably, the use of LaTeX which has been used extensively by blind authors to create mathematical expressions does not lead to a document that is readable by those authors.
Statistical software	Not all statistical software can be used by blind students. Efforts to improve accessibility of a number of commonly used options are ongoing, but at the time of writing, the authors can only unconditionally support use of R or SAS.
Online learning platforms	Most online platforms will be accessible to the extent that accessible material is used for its creation. For instance, uploading a pdf file will not help much, but adding an HTML document, where the mathematical content is presented through MathML, may offer great accessibility.

8. Conclusion

We accept that the mere presence in lectures of a blind student who requires more support with the right software tools and more accurate and more precise wording will make work for most statistics teachers. We are sure, however, that the alterations sighted teachers make to their own skill sets will improve the quality of teaching, and we wish to thank those teachers who choose to rise to meet this challenge. Those teachers wondering how to start this transformation should review our summary of adjustments provided in Table 6 where we have given our evaluation on the difficulty of making the adjustment and its likely impact value.

Finally, we now offer a gold standard for an accessible statistics course that would allow blind students to have full access to the same material and learning outcomes as their sighted classmates. An accessible course would need:

- an opportunity for the student to engage with the course staff before the semester begins, and ongoing contact with a key staff member throughout the course (this could be a tutor rather than the lead staff member for the course).
- An online teaching environment that is accessible, including access to the full range

Table 6: Adjustments that lecturers could consider in preparing to teach a blind student. The authors' opinion on the difficulty and impact are provided.

Topic	Adjustments	Difficulty	Impact
Starting out	Ask the question "What can I do to help you?"	easy	high
Language	Know the preferred term for the student's vision status	easy	medium
	Enrich spoken and written explanations of graphs in a context sensitive manner	easy	high
Documents	Provide all files in a readable format	medium	very high
Tactile images	Create images that are useful for the student	requires specialist equipment	varies
Tests/exams	Ensure the reader/writer to assist the blind student is comfortable with the material	easy	very high

of functionality such as course diaries, quiz and test modules, question and answer forums including the ability to author any content in questions, grade books, etc. The accessibility must be confirmed before the course commences by an expert who knows how the blind student will work using their adaptive technology; this confirmation must also address the aspects of the online teaching environment that pertain to a course in statistics not just general accessibility.

- All course notes (including study guides and textbooks) to be available in HTML, MS Word, or another accepted format (possibly the source LaTeX files) with all equations presented in such formats as can be read by the student. This will allow the student to convert the material into the braille format of his or her choice if appropriate. This material must be available well before the course begins.
- All lectures recorded so that blind students can marry up their own notes, the lecturer's notes or slides, and the actual comments made by the lecturer.
- All documents and copies of slides need to be provided before the class starts.
- All graphics to be optimised for embossing into tactile images as well as sufficient verbal description to make it possible to work without the tactile images once an understanding of the different graph types is gained.
- All assignment questions and feedback to be supplied in readable formats.
- The statistical software used for the course must be accessible. A blind student should not have to work alone because they are using different software to their classmates. Currently this means using R or SAS.

- Access to an embosser so that tactile graphics can be created on demand.
- All examinations and tests to be presented in a format that can be read by the student; they should not be dependent on access to a suitably qualified reader/writer, but when such human assistance is requested, the person must be comfortable with the statistical material of the exam/test. If testing is to be completed online, it must be evaluated for accessibility before the candidate takes the test.
- All exam/test/assignment questions must evaluate the knowledge of what graphics could/should show rather than what graphics do show. The use of pen and paper style examinations will need to be replaced by more interactive modes of examining a student's knowledge.
- Reasonable accommodations for examinations should be considered before the start of the course. That may include judging whether imposing a time limit on tests is necessary or allowing the student use of a computer with all necessary software so he or she can answer questions efficiently and effectively.

We know the above list is possible given the range of tools that already exist. We realize, however, that changing a course to cater to a blind student with this "wish list" is hugely impractical unless a long lead time for preparation is available. It is therefore understandable that a more pragmatic approach to meeting the blind student's needs will be taken by most teachers today.

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