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'A picture is worth ten thousand words': A module to test the 'visualization hypothesis' in quantitative methods teaching

Abstract

Inadequate quantitative methods (QM) training provision for undergraduate Social Science students in the United Kingdom is a well-known problem. This paper reports on the design, implementation and assessment of an induction module created to test the hypothesis that visualization helps students learn key statistical concepts. The induction module is a twelve-week compulsory unit taught to first year UK Social Science students which they complete prior to a more traditional statistical, workshop-based QM module. A component of the induction module focuses on the use of visualization through Geographic Information Systems (GIS), to teach the process of hypothesis generation to students while they also are introduced to the basics of QM research design and univariate and bivariate forms of data analysis. Self-reflexive evaluation indicates that visualization could assist students with more advanced QM statistical skills.

Background

Statistically numerate and critically informed Social Science graduates are vitally important to the British economy (British Academy 2012). Yet QM provision varies in the United Kingdom (UK) (MacInnes 2009, Parker et al. 2010, Linden 2012). Inadequate numerical skills are noted as a problem across the UK (McVie et al. 2008, Lynch et al. 2007). Curriculum initiatives have been sought by British funding councils and learned societies (Nuffield Foundation, ESRC, HEFCE 2012) to ameliorate the quantitative skills deficit (Chamberlain et al. 2014).

Graphical methods are a powerful means of conveying statistical messages to less numerically literate audiences, as effectively exemplified by Prof. Hans Rosling (2014) in productions such as 'The Joy of Statistics' (BBC, 2013). Visualization has been proposed as a mechanism to teach QM to Social Science students more effectively (MacInnes, 2012). This recommendation follows Parker et al. (2010) who assert, based on a review by Garfield and Ben-Zvi (2007), that '*exploring visual aspects of data helps students to learn basic statistical concepts*'. Visual approaches are also more widely advocated, for instance for younger students (Sobanski 2002, Balka et al. 2007, Lewis 2010). Moreover, the belief that a visual approach conveys an idea more effectively than words is succinctly expressed in the saying "A picture is worth ten thousand words" (Larking and Simon 1987:2).

The work reported in this paper is part of a research project (see Chamberlain et al. 2014) to provide an evidential base to assess the use of visual methods in QM teaching to Social Science undergraduates, who are typically anxious and report low levels of statistical ability (Unrau and Beck 2004, Zeiffler et al. 2008). Utilising developments in visualization software is commonly argued to improve performance at all mathematical levels (e.g., Kim and Kim 2003, Eliëns and Ruttkay 2009), and may lead to innovative QM teaching (MacInnes 2012). However, the authors of this paper chose to integrate visualization through with mapping technology (McEachren 2004, Smith et al. 2013), because mapping technology is seen as being increasingly important for employers and social science research in a range of areas e.g., poverty, health, and crime (Lloyd 2001; Riner et al. 2004, Boba, 2005).

The visual component of the QM induction module was structured around an experiential learning model (Kolb 1984), problem based learning (PBL) (Solem 2001) and continuous feedback and reflection (Fink 2003) with a focus on hypothesis generation and repeated interaction with key statistical concepts. Experiential learning or 'learning by doing' is a cyclical process based on the idea that experiences gained through activities (for instance, real life experiences or simulated in a learning context) facilitate learning (Fry et al. 1999). Despite the critiques of Kolb's experiential learning model (see for instance Kayes 2002), it remains one of the most influential learning model (Healey and Jenkins. 2000). As it will be explained in the next section, it is composed of four distinctive learning stages all of which are important for attaining effective learning. While the Kolb's model describes the process through which the GIS workshops were organised, PBL - defined as 'the ability to conduct independent inquiry into real-life issues' (MacVaugh 2009: 1) – presented real problems to students with the aim to elicit their interest and drive their learning (for a useful list of web resources for PBL see HEA 2005).

The module used Geographic Information Systems (GIS) to support this approach through the use of aspects of the process of visualization that include the 'exploration' of

data (MacEachren et al. 2004; Smith et al. 2013); the aims of this being (i) to support students throughout their course, (ii) introduce the key statistical concept of hypothesis generation, and (iii) alleviate student anxiety of QM.

The GIS component

The GIS component is part of a twelve-week induction module for first-year students enrolled either in a BSc (Hons) Sociology programme or BSc (Hons) Criminology and Social Policy programme. The module is delivered in Semester One, preparing students for a second part more traditional QM statistics module taking place in Semester Two (see Chamberlain et al. 2014). The module consists of eleven one-hour long weekly lectures and ten weekly workshops lasting two hours, with the GIS component delivered in its last five workshops (Table 1). The initial five weeks were designed to introduce students gradually to key concepts (research design, sampling, levels of measurements) that are prerequisites for the hypothesis generation work in that the GIS element aims to illuminate. The lectures introduced the theory, while in order to lessen students' fear of QM the workshops put the theory into practice in an environment which facilitated interaction with the tutors. Critically, numbers and equations were avoided in teaching the concepts with the intention of avoiding students erecting barriers towards QM.

GIS-based visualization is thought to motivate students in their learning, with stimulation tools being used to explore patterns and relationships between visualized variables (Orford et al. 1998, Forbes 2012). These aspects of visualization have been described in a framework consisting of four functions; from 'exploration' and 'analysis' of data to the 'synthesis' and 'presentation' of information (McEachren et al. 2004, Smith et al. 2013). The GIS component was designed in this framework with the intention of pushing students beyond the presentation of static images into the exploration area of visualization 'space' (McEachren et al. 2004).

The problem-based learning approach used during the GIS workshops aimed to stimulate and drive student learning by setting a 'question' (Solem 2001). This provided a subject-relevant focus for each workshop, directly developing students' ability to investigate social data. The questions (Table 2) reflect real issues in criminology, social policy and sociology, which students explored through active learning (Horton, 2001) following the experiential learning cycle (Kolb, 1984). The structure of each workshop and its relationship to the stages of the cycle are shown in figure 1 and described below. In another level of cyclicity, although they used a progression in the statistics employed (Table 2) the four main workshops deliberately contained similar and repeated aspects. The intended purpose of the repetition was to reduce student anxiety through accustoming them to similar scenarios where hypotheses needed to be formulated. A fifth workshop focused on how to produce clean, well laid out maps which students would then include in their project work.

[Figure 1 here]

Each workshop started with a presentation by the tutor, followed by a guided exercise and an assignment. The tutor's presentation introduced the 'problem' using relevant data from the Crime Survey for England and Wales, the Index of Multiple Deprivation Crime Dimension and 2011 Census data; concrete experience (CE) in the Kolb cycle. After this, students experienced the set 'problem' hands-on through a guided exercise. Each guided exercise had a geographical focus on the students' locality (i.e.,

Leicestershire) and took them through the process of hypothesis generation which underpins all inferential statistics. These exercises were punctuated by reflective observation (RO), as this enriches active learning (Fink, 2003, Wall 2013), and interaction with tutors. Throughout each exercise students had to explicitly reflect on the data visualized, the patterns identified, and specifically reflect on the problem through their personal knowledge or academic theories. In the course of these reflection steps students were led to summarize their thinking about the patterns identified through the development of null and research hypotheses: abstract conceptualization (AC). Students were thus prepared for the main AC stage of the cycle, which is the presentation of findings in the form of maps and a short report after undertaking active experimentation (AE) in doing the assignment. The assignment required students to choose their own variables and go through the visualization 'functions' of exploration and analysis of geographical patterns, followed by synthesis and presentation of findings in the form of maps and a short report. To provide further support feedback, which is conducive to deep learning (Fry et al. 1999) - that is learning aimed at understanding rather than reproducing material for the purpose of passing an exam (Case 2008) - was given to each student on a draft of their assignment (Figure 1), after which students would revise their work.

So, while the 'GIS problem-based learning cycle' of the induction module was developed to test the assertion that 'exploring visual aspects of data helps students learn basic statistical concepts' by considering hypothesis generation, the GIS component also implements other principles of effective teaching of statistics (Garfield and Ben-Zvi, 2007), by providing an environment where students can learn by (i) constructing knowledge out of their coursework, (ii) being actively involved in learning activities, and (iii) receiving timely feedback.

The GIS component in practice

The GIS component was developed with the use of the mapping software ArcMap10.1, part of ArcGIS desktop (ESRI). As the main purpose of the GIS component was to help students familiarize themselves with the process of hypothesis generation and lessen their anxiety towards QM, the use of ArcMAp was carefully structured in order to minimise technical problems which may hamper learning. This was achieved by detailed step-by-step instructions within the exercises and by strongly advising students to use ArcMap during the workshop session where technical help could be provided in person by the tutor.

The first two GIS workshops illustrate well the methods and principals used, so the rest of this section will examine them in more detail. The first GIS workshop was on learning how to generate a research hypothesis about a single variable (i.e., crime). Students were guided in the visual investigation of the geographical patterns with the question: *Is crime higher in urban areas than rural areas*? To investigate this, students were asked to inspect colour-coded maps (e.g., Figure 2) which displayed crime data for Leicestershire; to identify spatial patterns such as whether crime is high or low in different areas and to consider how the use of colour affects readers' visual impression of the underlying data (Mitchell 1999). Specifically they were asked if high crime levels are displayed in urban areas compared to rural areas. Then, students converted such questions, as an example:
- Crime levels are greater in urban areas than in rural areas in Leicestershire (Research Hypothesis; H_o)

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- There is no difference in crime levels between urban areas and rural areas in Leicestershire (Null Hypothesis; H_1)

The assignment replicated this procedure for another variable of each student's choice.

[Figure 2 here]

The statistical aim of the second workshop was to generate research hypotheses about the relationship between the two variables and interpret them. The question asked for the guided exercise was: *Is there an association between crime and fear of crime*? Students generated hypotheses and expectations of any link based on their visual interpretation of the two variables, initially on a scatter plot (Figure 3). They formulated testable hypotheses:

- H_1: There is an association between Crime score and Fear of crime
- H_0: There is no association, and any apparent link results from random variation or measurement error in the selected sample.

Then they investigated these variables on maps to include the spatial information which a scatter plot cannot (Figure 4), and refined their hypotheses and expectations accordingly, for example

- H_1: Levels of Fear of crime are greater in urban areas where crime is high than in rural areas in Leicestershire where crime is low.

[Figure 3 here] and [Figure 4 here]

The assignment replicated the guided exercise, students selected either the crime index or the fear of crime variable and explored its association with another social variable of their choice from the 2011 Census.

Student assessment

The induction module has a weighting of ten credits, and represents 100 hours of directed and self-guided work. It is summatively assessed through a portfolio, with the four GIS components comprising 50% of the total (Table 3). Such a portfolio of achievement (Hounsell et al. 2007) is well suited to evaluating students' progress in understanding key concepts (Thomson et al. 2008). It was also intended to support the students' learning.

Firstly, one of the intended functions of the induction module was to relieve students' anxiety by introducing continuous formative assessment, which emphasises how much they have learned (Rust 2002). Providing feedback to students throughout the GIS workshops was included to promote deep learning as students could understand and progress from their 'mistakes'.

Secondly, a key factor in the module design was the focus on getting students to positively engage with QM. The GIS weekly assignments were intended to encourage students to take ownership of their learning, a sort of 'homework' (as one student put it), supplemented by the dedicated time in each workshop to work on the assignment while tutors were present.

To deter disengagement an approach was adopted where students were asked to present an acceptable first draft of their GIS assignment for 'signing off' by a tutor before the end of the subsequent week's practical session. A 'good draft' included sections stating the hypotheses and a number of relevant maps, and verbal feedback was given

individually. This one-to-one exchange between tutor and student gave also the opportunity to students to ask questions.

Final, compiled summative portfolios included at least the formatively assessed materials from the workshops, but students were free to move beyond this minimum requirement. For the GIS component of the module, assignment templates were provided (see appendix) with the intent to support students with the development of a 'good draft'. A 'reflection' document reporting student thoughts on their learning was also required to be in the portfolio. Though the document had no influence on the final module mark, it was designed to enhance student engagement, but also it provided pedagogical evidence of the impact of the course. Although the portfolios were not anonymous, students appeared to feel free to provide frank comments as evidenced by some critical but constructive comments on the use of GIS mapping. This augmented the information gleaned by the tutors as they used the formative feedback provided to monitor progress towards the intended learning outcomes. Students were also able to provide continuous feedback through weekly interaction with tutors. As in the cohort prior to this one (Chamberlain et al. 2014), an identical survey at the beginning and end of the module demonstrated that students are anxious about QM.

Self-reflexive evaluation

Critical reflection involves carefully considering how a learning activity went (Schon 1983), with the aim of improving students' learning. Reflections that considered what went well, what worked less well and suggested potential changes to the GIS course, were gathered by the tutors during its delivery. The high level of student-tutor interaction and the 'reflection' document within the submitted portfolios also meant that tutors could reflect (reflection in action) through the eyes of the students.

A reflective cycle (Gibbs 1988) provides relevant questions in order to structure reflection around Kolb's experiential learning cycle. Specifically, a focus of educators is on whether students can relate 'theory to practice' (Brigden and Purcell 2004: 21). Here, the varied evidence is assessed in order to evaluate how well students related 'theory to practice' throughout the GIS workshops, and so assisted the induction module to achieve its aims.

Four main themes summarise the reflections of the students and instructors and provide a provisional answer as to whether (i) students felt supported, (ii) students related the theory of hypothesis generation to the GIS workshop practice, and (iii) visualization can lessen students' anxiety towards QM.

Theme 1. The learning cycle
Students typically found the repetitive, cyclical approach to hypothesis generation useful. For instance, many found the process of hypothesis generation for two variables easier because they had already done similar work for one variable. Feedback from the tutors was used to develop their learning. In particular an important moment of the learning cycle was the review of the GIS draft and the feedback received from the tutor would allow students to produce an improved final version of their GIS assignment which reflected their increasing understanding. Indeed, some students habituated the process of hypothesis development. Unfortunately, this also resulted in instances of uncritical repetition of the same formula whatever the topic, missing the vital point that research hypotheses should be tailored to a specific question. As an example, workshop GIS 3 required students to develop hypotheses about whether the majority of

people in Leicestershire live in areas of high crime, but some students completely ignored the question and focused on a related but tangential question about the link between crime and population density covered in GIS 2. Based on student-tutor interaction for workshop GIS 3 and feedback provided to students, it was noted that some students found it difficult to 'estimate' the majority of people in Leicestershire and consequently opted for an easier (in their view) albeit tangential answer to the assignment question. Tutors related this difficulty to the fact that some students were unwilling (rather than unable) to 'estimate' i.e., to engage with 'numbers' (this issue will be explained in *Theme 3. Student anxiety towards numeracy*). There is evidence that the cycle approach to learning meant that students felt supported as intended by one of the aims set, though there is mixed evidence regarding the ability to relate the theory about hypothesis generation to the GIS practice.

Theme 2. GIS technologies and visualization
The focus of the induction module was to learn *with* GIS about hypothesis generation rather than learning *about* GIS, and the intention was to avoid the technology hampering the learning process rather than facilitating it. This is non-trivial to achieve as GIS packages are complex and require technical ability. No technical problems were experienced, so the presence of tutors and detailed instructions sets appear to have worked. Students who thought the software was difficult to use or experienced technical problems were those who had not attended the workshop and were trying to catch up in their own time.

While a minority of students thought that 'looking at maps' was not relevant for their sociology course, during the workshops it was generally observed that students engaged with the technology in the sense that it was clear to them that the focus of their work was the hypothesis generation process, as highlighted in several student reflection documents, rather than GIS. The aim to introduce the key statistical concept of hypothesis generation through GIS seems to have been fulfilled, i.e., the mapping tools utilised throughout the workshops were a means towards a learning outcome (understanding the hypothesis generation process) rather than an end in itself.

Theme 3. Student anxiety towards numeracy
The GIS course seems to have eased student anxiety toward numeracy, as one student observed: "I do not *feel confident* learning about [numbers] but I am *becoming* increasingly *confident* through the module". Throughout the GIS workshops, the tutors also observed raised student confidence in engaging with other QM concepts (for instance sampling and levels of measurement) that had been dealt with in earlier non-visual workshops and a willingness to revise those assignments because of their increased understanding. However, observations in the workshops also showed that some students prefer not to engage with numbers (as reported in *Theme 1.The learning cycle*), even with the use of visualizations such as dot density maps (Figure 4). A minority of students found it difficult to link the number of dots in an area to the number representing the proportion of people in fear of crime. Others explained the dots as the actual location of people in fear of crime, even if the presentation and the guided exercise made it clear that dots did not indicate location of people. The misreading of dot density maps by some students might be the result of a mismatch between these students' learning preferences, (who might be, for instance, 'verbalizers' rather than 'visualizers') and the visual (GIS) learning and teaching approach used (on the issue of learning styles see Felder and Spurlin 2005, for instance). However, a match between student preferred learning styles and learning method used (i.e., using visual methods only with 'visualizers) do not necessarily result in better learning outcomes as cognitive

ability (in particular 'spatial visualization') seems to have a more prominent role in learning outcomes than learning styles only (Kollöffel, 2012). In fact, during the course of the GIS workshops it was noted that for some students increased easiness with visualizations was matched by an increased easiness about the hypothesis generation process. However, as this evidence is anecdotal more research on the issues of visual learning styles and teaching methods is warranted.

If student understanding of visual aids (e.g., maps or graphs) is fully formed they can assist learning (Booth and Koedinger, 2012), but in contrast Garfield and Ben-Zvi (2007) recognise that students fail, if not carefully guided, to use graphs as reasoning tools, and instead employ them as illustrations. For this reason, as explained above, several methods were used to ensure that GIS facilitated rather than hampered learning i) tutor-led introduction to the task ii) detailed step-by-step instructions, and iii) the continual presence of tutors and teaching assistants who pro-actively engaged the students.

Theme 4. The wider context
As a corollary of the significant interaction and feedback, the course was time and resource intensive for both students and for instructors. A positive aspect of this was that students appreciated repetition, interaction with tutors and fellow students, and spending time in the classroom as this gave them time to assimilate their understanding of key concepts. Feedback was particularly appreciated. For instance, during each GIS workshop the original plan was to provide each student with 2-3 minutes of verbal feedback. In practice 5-10 minutes was required in order to provide detailed suggestions. A further strain was placed on resources by student requests for feedback outside workshop time, although this could be dealt with by (i) using online learning environments to handle more queries in a forum rather than individual basis (ii) expectation management (iii) and self-support in groups.

It seems that on balance the GIS component achieved the aim of introducing students to the hypothesis generation process in a non-technical manner, though the full assessment of the induction module impact will only be clear after the conclusion of the more traditional QM module at the end of semester two (June 2014). A full assessment of impact also will be conducted following the completion of the research project which is currently collecting and analysing data to explore student anxiety issues before and after the implementation of the induction module (Chamberlain et al. 2014).

Conclusions

Based on student feedback and tutors' self-reflective evaluation, the following conclusions about the GIS component of the induction module can be drawn.

Visualization using GIS appears to have the capacity to lower the barrier to some QM concepts for some students. Specifically, it can introduce key concepts (i.e., hypothesis generation) in QM without the use of numbers. The extent to which shielding students from their anxiety towards numeracy is an effective learning approach which helps them when they are faced with a traditional QM module, however, is open to debate. A more robust answer will be provided once the full impact of this approach is assessed in June 2014.

In line with previous work, students respond positively to repetitive learning when facing difficult concepts and to a high level of interactivity, and may just have found the work

less daunting as additional curriculum time was targeted at it. These effects, however, are difficult to disentangle from anecdotal evidence, which will require analysis of questionnaire data collected before and after the implementation of the induction module.

Given the initial positive results of a visual learning and teaching approach, the authors of this paper would also consider integrating statistical visualization software (Garfield and Ben-Zvi 2007, McInnes 2012) together with the GIS component in order to develop a fully visual module. However, it is important to reiterate the findings of previous work that the additional effort may not be repaid unless QM teaching is integrated fully into the curriculum (Chamberlain et al 2014).

Notwithstanding the relatively small sample (85 students) of the study, it is clear that students respond positively to feedback, interaction with tutors, formative assessment and the 'GIS problem-based learning cycle', but while the high level of interactivity in the course made it time and resource intensive, in the future solutions can be sought through the use of online learning environments and 'self-help' forums.

All the materials of the GIS component together with the rest of induction module will be available for use across the social sciences in July 2014.

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	Lecture Topic	Workshops topic
Week 1	Introduction to the Module	
Week 2	Research Design	Research Design
Week 3	Sampling	Sampling
Week 4	Descriptive Statistics	Levels of Measurements
Week 5	Hypothesis Generation	Student presentation
Week 6	Progress Review Week	GIS 1
Week 7	Bivariate Analysis 1	GIS 2
Week 8	Bivariate Analysis 2	GIS 3
Week 9	Consultations	GIS 4
Week 10	The Social World	GIS 5
Week 11	Assessment Support	Individual consultations
Week 12	Submission of Portfolio	

Table 1 Induction Module Structure

GIS Theme	PBL Question for guided exercise	Activities and Statistical Points
GIS 1: Thematic Mapping	*Is crime higher in urban areas than in rural areas?*	One variable, with the use of thematic mapping • Interpret a colour-coded map; • Define and colour crime classes (e.g., high, low) differently to understand how this affects visual impression; • Identify spatial patterns in the data; and • Convert this inspection into hypotheses about crime levels. • Explain what it would mean to reject or accept the null hypothesis.
GIS 2: Bivariate & Proportional Mapping	*Is there an association between crime and fear of crime?*	Two variables, with multivariate mapping • Interpret visually any association between crime and fear of crime using a graph called a scatter plot; • Formulate testable hypotheses based on this; • Investigate how different maps display these variables including their spatial patterns; and • Refine your hypotheses accordingly. • Explain what it would mean to reject or accept the null hypothesis.
GIS 3: Cartograms	*Do you think that more than 40% of people in Leicestershire are in fear of crime?*	One variable using distorted maps named cartograms (Dorling, 1996) • Visually examine an undistorted map of 'Fear of crime' as used in previous workshops; • Decide if it indicates that most people live in fear of crime; • Formulate hypotheses for this observation; and • Examine a cartogram of the 'Fear of crime', and comment upon any changes in your confidence that the hypotheses are true.
GIS 4: Patterns & Clustering	*Does crime cluster in 'hot spots'?*	'Clusters' using the results of a cluster analysis test. • Visually identify clusters of high and low crime in Leicestershire; • Use this to generate research hypotheses; • Compare your clusters to those produced by a numerical analysis, and consider the differences; and • Generate hypotheses from the results of the numerical analysis i.e., Anselin Local Moran's I (Anselin, 1995). • Explain statistical testing in terms of random trials.

Table 2 GIS course structure, problem-based questions and activities

Portfolio element	Weight
Research Design	10%
Sampling	10%
Levels of Measurements	10%
Oral Presentation	10%
Hypothesis Generation	10%
GIS project work	50%

Table 3 Portfolio elements and weights

Appendix

Template for GIS 1 Assignment

Title e.g., *An investigation into the distribution of crime in Leicestershire*
[Short and concise]

Aims
[Briefly explain what you plan to do. Bullet points are acceptable]

Background
[This should explain the context of your proposed analysis. This can be based upon your general knowledge or popular press, but you should support this by referring to the primary literature on crime (i.e., books or journal articles). Note that this is <u>not</u> a literature review. For instance, refer to literature that can support your hypotheses regarding the distribution of crime in urban and rural areas].

Graphics Methods
[Describe what data you used for your analysis and why. Explain how you plan to display the data and justify why – be specific about which visualisation option you selected and why etc …]

Visual Analysis
[What are the results of your analysis? Explain your findings in the context of the literature referred to in the background i.e., set up the justification for the null and research hypotheses

Hypotheses
[Full statement of the hypotheses and precisely what testing these (either visually or numerically) will allow you to determine]

Conclusion
[Brief summary statement of the conclusion of your analysis i.e., research hypothesis, your best estimate of you confidence in it, and likelihood of being able to reject the null hypothesis]

References
[Correctly formatted reference list. If in doubt, please refer to your department's referencing guidelines.]

List of figures