TEACHING STATISTICS TO ENGINEERING STUDENTS: THE EXPERIENCE OF A NEWLY APPOINTED LECTURER

Irene Biza

Loughborough University, UK

In this paper I will adopt the reflective practitioner approach (Schön, 1987) to analyse the experience of a newly appointed lecturer in teaching statistics to engineering students. The lecturer is seen as entering a new for her community of practice (Wenger, 1998), the community of teaching mathematics at university level, which does not necessarily have universal characteristics. Different (sub)communities of students, lecturers and researchers are involved and in some sense affect teaching decision-making. Observations indicate that these communities interact to each other with potentially contradictions and affect the experience of the new lecturer.

Keywords: Teaching Statistics, Reflective practitioner, communities of practice, undergraduate mathematics teaching

INTRODUCTION

The last two years I have been offering a module on Statistics to engineering students in a well-regarded university in the UK. I am a mathematics graduate, I used to be a mathematics teacher and currently I am a researcher in mathematics education. When I started, two years ago, it was the first time I offered a module to a big group of engineering students and the first time I taught Statistics. In this paper I will offer an account of my reflection on this experience. I will adopt the *reflective practitioner* approach (Schön, 1987) to analyse this experience in two directions: the experience of teaching Statistics to engineering students and the first year experience of a newly appointed lecturer. I can see a newly appointed lecturer as a person entering a new community of practice (Wenger, 1998), the community of university lecturers. This community does not necessarily have universal characteristics. It seems that there are different (sub)communities that are involved and affect teaching decision-making and practices. In the experiences I am going to discuss in this paper I will consider the context and the different groups of people involved – engineering students, lecturers of Mathematics or Statistics, statisticians, etc.. These groups can be seen as communities with characteristic practices. Drawing on my teaching practices and the feedback I received from the students, I will present three incidents related to: introduction to theory; creation of adequate intuitions; and, critical use of formulae.

In what follows I present the theoretical construct on which my analysis was based, a brief literature review on the above mentioned topics, the methodological approach and some observations related to these topics. Finally, I discuss some potential implications of this reflection to teaching practices at university level.

THEORETICAL CONSTRUCT

According to Wenger (1998) communities of practice are formed by people who engage in a process of collective learning in a shared domain of human endeavour. In these communities people are involved in activities that have same objectives and share a concern or a passion for this and learn how to do it better as they interact regularly. Learning is not necessarily the reason one community comes together as it might be the incidental outcome of member's interaction. On the other hand not any community or a group of people (e.g. a club, a neighbourhood or a company of friends) can be called a community of practice. A combination of three elements constitutes a community of practice: the *domain*, the *community* and the *practice*. The community needs to have a shared domain of interest that defines an identity of its members, who commit themselves to this domain, engage in joint activities and discussions, help each other and share information. A relationship is built between members and enables them to learn from each other. However, common interests are not enough to establish a community of practice – as, for example, in a film club. Members need to have a shared practice, namely a shared repertoire of resources such as experiences, stories, tools or ways of addressing recurring problems.

Research discusses several communities of practice related to teaching and learning of mathematics especially at university level: undergraduate students, mathematicians or mathematics education researchers. These communities are characterised by particular practices and ways of communication and potentially interact with each other. Solomon (2007) investigates potentially conflicting communities of practice within which undergraduate students find themselves, and presents a typology of their related learner identities. Additionally, Wenger's community of practice construction has offered a theoretical framework for the analysis of students' beliefs about mathematics and their self-positioning within the school classroom or university lecture theatre community (for students beliefs about proof, see Solomon, 2006).

In a developmental research project for engineering students' conceptual understanding of mathematics, Jaworski and Matthews (2011) regard university an institutional environment with "norms and expectations which can be seen to form an established community of practice" (ibid, p. 179). The elements of this community regard the curriculum, the assessment, teaching arrangements (e.g. timetables, location etc.), student culture and expectation and teacher culture and expectation. Lecturers are "aligned with all of these to some extent and there are differing degrees to which change is possible" (ibid, p. 184).

Nardi (2008) describes mathematicians and researchers in mathematics education as two different communities with overlaps and conflicts that tantalise their relationships. She discerns the fragility – but also the importance – of the relationship between these two communities. Mathematicians admit the benefits of pedagogical practice being informed by mathematics education results, reflect – often with scepticism – on research in mathematics education practices (theoretical and methodological) and acknowledge the influence of stereotypical perceptions on mathematics, mathematicians and educational research in their relationship (ibid, p. 257-292).

In my reflection on teaching Statistics to engineering students I can see different groups of people being involved: engineering students; lecturers of Mathematics or Statistics for specialist or non-specialist students; statisticians; users of statistics; and, researchers in mathematics education. These groups can be seen as communities with characteristic practices. There are overlaps between these groups and some of them might be seen not so realistic. This might be true. However I found this construction very helpful on my teaching reflection and I will refer to some of these groups in my account in this paper. Putting myself in this spectrum of communities, at the time I was appointed, I was a mathematician (graduate of mathematics but not researcher), I had been practitioner in mathematics teaching, I was an active researcher in mathematics education, and I was a user of statistics in educational research.

ISSUES RELATED TO THE TEACHING AND LEARNING OF STATISTICS

Lecture is a widespread mode of teaching at higher education in the UK, especially in mathematics and engineering departments. Usually it is accompanied by smaller group tutorials. There is a scepticism and sometimes critique on lecturing as an effective teaching method for students' learning (Biggs, 2003). However we cannot ignore that numerous cases of lectures have been highly rated by the students (Morton, 2009) and that both students and academics see value in this type of teaching (Folley, 2010). In the case discussed in this paper the big group lecture was the only teaching option and this characterise unavoidably the interaction between lecturer and students.

Statistics is "often regarded as being difficult to understand" (Kyle & Kahn, 2009, pp. 258). Several challenging aspects of the statistical concepts have been highlighted in research: the formulation of hypothesis; the distinctions and the application of different types of tests; the interpretation of the results (especially regarding the recognition of the significance level); and, the understanding the terminology used in stating a decision (Batanero et al., 1994). Garfield (1995) proposes five scenarios to support students' understanding of statistical concepts: activity and small group work; testing and feedback on misconceptions; comparing reality with predictions; computer simulations; and, software that allows interaction. Especially for non-specialist of statistics students, data-driven approach to the subject without insight to the mathematical foundation of the concepts is recommended (Kyle & Kahn, 2009).

Statistical teaching had changed dramatically in the last two decades. Older instructions used to be dominated by probability-based inference, abstract approaches with emphasis on memorising of formulae and techniques. A modern approach offers more opportunities for students' engagement with authentic activities. Also, this approach includes a more balanced use of the steps of data production, data analysis and inference. The transition between these steps has a lot of *back and forth* critical movements and it is not anymore straightforward as it used to be in the traditional statistical calculations (Moore, 1997). This modern approach is at an epistemological conflict with the formalist mathematical tradition and the persistence of students' difficulties in statistical reasoning might be the result of the continuing impact of the formalist mathematical tradition (Meletiou-Mavrotheris, 2007).

I discuss some of these issues regarding the teaching and learning of Statistics in the examples from my experience I present in the following.

METHODOLOGICAL APPROACH

Throughout the academic year I had been keeping reflective notes on my experiences, annotated lecture notes with my comments just after each session and notes on my occasional communications with my colleagues. The observations I present in the next section draw on these resources and my background readings. I can consider myself as a *reflective practitioner* in the terms of Schön (1987). There are studies in which practitioners develop their reflection on practice while they are working with researchers in mathematics education (Jaworski, 1998; Nardi, 2008). In the case presented in this paper the arrangement is different as the researcher in mathematics education (myself) becomes a practitioner and develops her practice in parallel with her interaction with other practitioners.

THE EXPERIENCE OF FIRST YEAR TEACHING

In this section I will discuss a Statistics module that was offered to a large group of 132 second year engineering students. This module is one of the service courses the Department of Mathematical Sciences offers to other departments. The students were from five different engineering programmes. Although all of them are engineering students their studying habits, needs and background vary across the subgroups. The teaching approach of the module is a combination of 11 two-hour lectures and 4 one-hour lab sessions using statistical software. As the module has been running without problems in a similar structure for several years, I used the existing module specifications without having any involvement to their design. The module is assessed through a coursework (20%) and written examination (80%).

When I started, two years ago, I had not taught a statistics module before and moreover I had not offered any module to engineering students. So, using Shulman's language the first challenge for me was to build a pedagogical content knowledge Shulman (1986) appropriate for this kind of teaching. This knowledge had to do not only with the statistical content that was necessary for these students (content knowledge) but also had to do with the pedagogy that should be adopted in this particular teaching (pedagogical content knowledge).

I was a newcomer in this *world* and I had a lot to learn from the long experience of my colleagues. I aimed to have informal contacts with lecturers who had similar modules or researchers on statistics. I also participated in informal discussion organised in my department for lecturers who offer mathematical or statistical courses to engineering students. In parallel I was attending the "New Lecturers Course" of my institution and regular seminars on "How we teach" offered by other lecturers of Statistics and Mathematics. I based my lectures on the plan and the lecture notes used in previous years with the support of the lecturers who had designed these notes in the first place. Recently, colleagues (including myself) have been forming a forum for members of staff at our institution with an interest in teaching statistics or quantitative methods, to enable us to meet and share ideas, experiences and resources.

In the next sections I present three examples from my practices in teaching, as I experienced them in my lecturing and my reflection, especially in relation to the groups of people who are involved or related to these teaching practices.

Example 1: Theoretical explanations: Are they necessary and to what extent?

In the first session I had to introduce students to basic concepts of probability theory. According to Kyle and Kahn (2009), students with a strong mathematical background would be able to cope with a theoretical foundation of the subject. On the other hand non-specialists of statistics would find a data-driven approach to the subject more beneficial. In agreement with this recommendation, the lecture notes from previous years included a very brief introduction to elementary probability without any reference to theoretical parts, such as set theory.

When I started designing my lectures, I found talking to my students about probability without introducing them to the basic concepts of the set theory impossible. How, for example, could we discuss the *addition law of probability*: $P(A \cup B)=P(A)+P(B)-P(A \cap B)$ without talking explicitly about sets, union and intersection of sets and their representation through Venn diagrams? For this reason, I added a brief section on sets (Figure 1a). Later on, I realised that the sets after their theoretical introduction turned out to be implicit components of the probability laws without any explicit reference to them. For example, no tasks on sets were included in the students' practice and exam questions. As a result, students ignored the sets and focused directly on the section on probability that was necessary for their tasks and their assessment. So by the end of the year I decided that, given the restricted time-schedule of the module, this choice would have been considered as a *waste of time*. The year after I deserted this section by keeping only the corresponding Venn diagrams in each one of the probability laws (Figure 1b) and I used more time on examples.

Thinking about this choice retrospectively I can say that it was my mathematics teaching background that pointed out a lecture that had all the necessary theoretical elements. I was looking for a structure that was theoretically complete without considering the students' needs and the practical constraints. In the language of communities of practice, I was coming from a community with practising in teaching mathematics for specialists to a community related to teaching application of statistics to non-specialists.

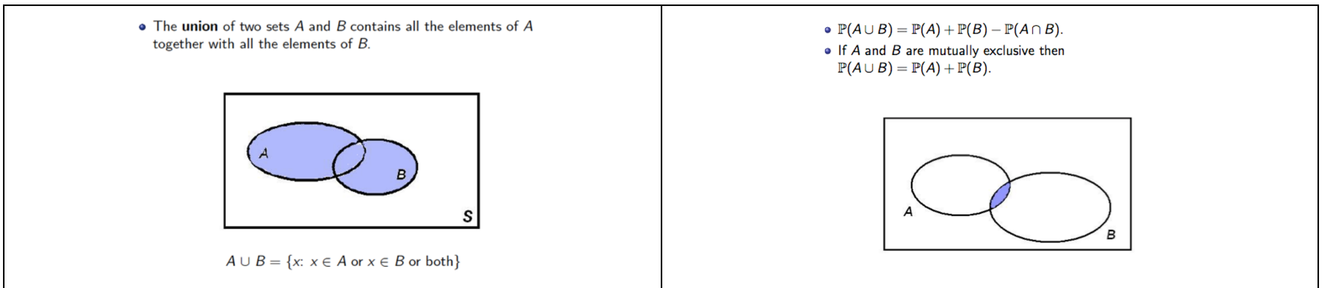

Figure 1a **Figure 1b**

Figure 1: Venn diagrams, sets and probability laws

Example 2: How can we help students create correct intuition about the processes they apply?

It is usual practice for users of statistics to interpret the results from statistical tables or outputs without necessarily understanding their meaning. In anecdotal conversations with colleagues who use statistics in their research or offer research methods courses, I heard that this is enough to make an accurate decision. Other colleagues believe that students need to be offered more explanations about these techniques in order to apply them and interpret the results properly. I see myself in the second group, as I believe that students will be more flexible and safer in their decisions if they know what is behind the procedures they apply. An unconscious use of a technical procedure without alternative confirmation methods may result in erroneous responses. A characteristic example is the interpretation of the *p*-value in the decision making of hypothesis testing: when the *p*-value is less than the significance level (usually in practice 0.05 or 0.01), there is a statistically significant result and therefore there is enough evidence to reject the null hypothesis. However students have trouble to interpret this result (Batanero et al., 1994). There are cases in which students, although aware of the need to compare the *p*-value with the significance level (e.g. 0.05), are not sure if the *p*-value needs to be *more* or *less* than this level. Alternatively, they would be more confident in their decisions if they were relying not only on their memory but on knowing the meaning of the *p*-value. With the above in mind, I decided to offer students different aspects of the same concept as backing to their decisions.

The expectation, in the mathematical community is the warrants of the arguments to be based on the theoretical foundations. In the community of engineers who use statistics and mathematics in their applications the warrants should be based on appropriate intuitions of the concepts. To this aim, in my teaching design, I tried to highlight the connection of different aspects of the same concept towards the creation of correct intuitions. In this endeavour, I acted by putting together my personal intuitions, the content knowledge as well as my pedagogical content knowledge from mathematics education. According to the latter, research suggests that different and interconnected representations facilitate mathematical understanding (e.g. Presmeg 2006). Also, the provision of different representation and the manipulation of different aspects of a particular representation appear to help students learn basic statistics concepts (Garfield, 1995). In this spirit, and regarding the example of the *p*-value I mentioned earlier, I tried to put together the result of a statistical test and the corresponding critical value in the distribution graph and explain on it the meaning of the significance level and the *p*-value (see Figure 2). I did this not only in the first introduction of the test but I kept using it in each one of the examples we discussed in the lectures. I aimed the graph to become a confirmation tool for the students in their statistical interpretation of the *p*-value.

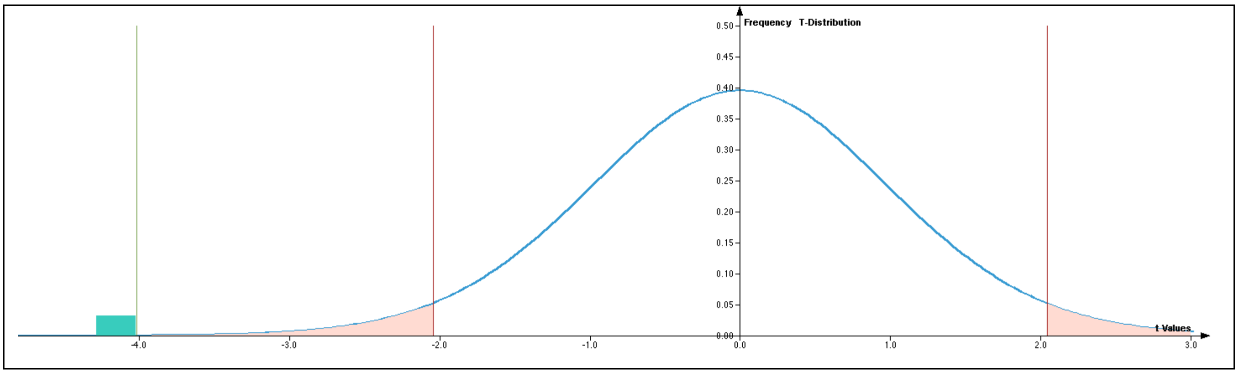

Figure 2: The statistical test and the critical value in the distribution graph

I do not have evidence that this approach was helpful to the students. In some cases I noticed little graphs made by students next to their responses in the exams. However, there were still students who misinterpreted the outcomes of the processes (e.g. by saying that there is significant difference when the *p*-value is more than 0.05) in the coursework and the exams.

In this incident my actions were strongly influenced by the community of mathematics education. However, students who act under the norms of their community did not necessarily follow my intentions. Although, lecturers may believe that representations are of student understanding's help – especially for us who are strongly influenced by mathematics education research – it's not always clear whether students notice these representations, what they see in them, or how they connect them. There are cases in which students interpret a representation differently than lecturer intends, and cannot see the mathematical meaning that is embedded in these representations. This is an area that calls for further investigation in two directions. One possible investigation is on what students really notice and how they connect different aspects of the same concept. Another investigation can be on whether students' practices are related to their community's practices, e.g. if their community is interested only in the application of methods, students might not put enough effort on the understanding of the meaning of this method.

Example 3: How can we help students to use formulae critically?

In Statistics many and complicated formulae are used. Usually, remembering these formulae is not necessary and very often more emphasis is put on the correct use of a formula instead of its memorisation. To this aim, formulae sheets are used for students' practice and their written class assessment. In the module I describe in this paper students practice both in applications of the formulae with calculator and in statistical analysis with software in the lab. The former is assessed through their final written examination and the latter through a written coursework in a form of essay. Throughout the term and in the exams, students use the tables and the formulae list from the Tables for Statisticians (White, Yeats & Skipworth, 1979). Additionally, they practice on examples from the HELM textbooks (Helping Engineers to Learn Mathematics (HELM) workbooks, http://helm.lboro.ac.uk/). The two resources use different versions of the tables and different notation in the formulae. For example, the formula I used in the lectures for the calculation of the *slope* in the *simple linear regression model* (the same as the one used in the HELM workbook, HELM workbook 43, p. 6) and the formula students had in the exams (White et al., pp. 65) are presented in Figure 3.

$$b = \frac{\dfrac{\sum xy}{n} - \dfrac{\sum x}{n}\dfrac{\sum y}{n}}{\dfrac{\sum x^2}{n} - \left(\dfrac{\sum x}{n}\right)^2}$$

HELM workbook 43, p. 6

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2}$$

White, Yeats & Skipworth, 1979, pp. 65

Figure 3: Simple linear regression formula

The mechanical application of a formula without understanding its meaning might result in some trouble. This trouble might be because of the different notations or because of the implicit algebra of a formula. I have been raising these issues in my lectures and let my students know from very early what formula sheet they would get at the exams. This is technical information that might be overlooked by the students as the following incident exemplifies:

> One of the students just after the exams emailed to me that the formula of the slope in the simple linear regression model at the lecture notes was *not correct* and although it took him some time to *memorise* it he was unable to give a correct answer to the exam question. Also, he said that this was *unfair*.

There are a couple of issues I would like to highlight in this incident. Firstly, it seems that for the student there was only one version of the formula and he was not flexible enough to see that the two formulae were equivalent. This is might be because of the notation or because of his inadequate algebraic knowledge. Also, he claimed that he spent so much time *memorising,* indicating a practice that was in conflict with what I have been trying to encourage my students to do. Finally, he assumed that limited learning resources (in this case lecture notes or/and HELM workbook) are enough for his preparation and he defend himself by saying that the formula in the notes was incorrect. It would appear that there is a conflict between lecturer' and student' anticipations. Lecturer expects university students to be individual and critical learners. However, the student expects specific study guidelines and transfers the responsibility for his learning (or his mistakes) to the lecturer. The two communities have different expectations regarding this responsibility as well as approaches to university study.

DISCUSSION

In this paper I presented examples from my inaugural experience of teaching Statistics to engineering students. While this account is not a systematic study, I draw on my reflections in order to discuss the complexity of the experience of a newly appointed lecturer especially when she comes from different teaching and research communities.

A first observation is that, although I tried to adopt a more modern approach in teaching statistics (Moore, 1997) with less focus on memorising techniques and formulae, students were still keen on a rather mechanical approach on learning. A second observation is the different identities through which I experienced my first year of teaching: mathematician, lecturer of statistics, university lecturer, lecturer to engineers and mathematics education researcher. The relationship of these identities was not always smooth and many contradictions occurred between them.

It seems that although we may consider ourselves as part of the broad community of practice (Wenger, 1998) of teaching undergraduate mathematics with shared practices and ways of communication, in practice other (sub)communities are involved and establish their rules. One of these communities is the community of students, which has its own regulations and interacts with the teaching community of lecturers – with some potential conflicts. Other (sub)communities are related to the mathematical content (e.g. mathematics or statistics) and the type of study programmes (e.g. prospective mathematicians or engineers). My enculturation to this new environment was not straightforward and the interaction with my colleagues was crucially helpful.

Here I report observations on how communities interact and how this interaction affects the experience of a new lecturer. Further, systematic research on this is needed.

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