A review of group-based methods for teaching statistics in Higher Education

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Abstract

The teaching of statistics in higher education in the UK is still largely lecture-based. This is despite recommendations such as those given by the American Statistical Association’s GAISE report that more emphasis should be placed on active learning strategies where students take more responsibility for their own learning. One possible model is that of collaborative learning, where students learn in groups through carefully crafted ‘problems’, which has long been suggested as a strategy for teaching statistics.

In this article, we review two specific approaches that fall under the collaborative learning model: problem- and team-based learning. We consider the evidence for changing to this model of teaching in Statistics, as well as give practical suggestions on how this could be implemented in typical statistics classes in Higher Education.

1 Introduction

University courses in Statistics have traditionally been given in the instructional style, in which a lecturer transcribes a set of notes for students over a course of lectures. In this process students are passive recipients of information. This method of delivery can be scaled up to cope with ever increasing class sizes, a crucial factor in determining which teaching methods could realistically be implemented, but the quality of the resulting education is questionable.

The American Statistical Association, however, specifically endorse a more active approach to teaching with students taking responsibility for their own learning [Carver et al., 2016]. Going further, the idea that Statistics education should resemble Statistics practice - relying on cooperation, communication, and
team-work - is clearly advantageous (Roseth et al., 2008) but rarely happens in higher education.

Collaborative learning, where students learn in groups through carefully crafted ‘problems’, has long been suggested as a strategy for teaching Statistics (Garfield, 1993; Carver et al., 2016; Roseth et al., 2008). Despite recommendations, Statistics education in higher education in the UK is still largely lecture-based, though the tide is slowly turning.

In this article, we review two specific approaches that fall under the collaborative learning model: problem- and team-based learning (PBL and TBL). These approaches have been used in many other disciplines to good effect, and we consider their adaptation to teaching Statistics. In Section 2 we describe both PBL and TBL, and consider the evidence for using these strategies - both specifically for Statistics and also more generally - in Section 3. In Section 4 we consider the practicalities of using these methods for the teaching of Statistics and offer tips for effective implementation.

2 Group-based enquiry-driven teaching methods

PBL and TBL have made their mark in a number of disciplines, including medicine and allied health professions, business, and engineering. Both approaches fall under the umbrella of ‘active learning’, where students learn through working on a sequence of carefully crafted problems in small teams.

The set-up, and therefore the nature of how students learn, is different. In PBL, the problem posed becomes the source of learning: students become independent seekers of information in order to provide a solution, but under the guidance of a facilitator. For TBL, however, students learn first by using resources made available by the instructor and class time is then dedicated to applying this knowledge to solve the problem in teams.

In this section we review the ‘classic’ implementation of both PBL and TBL. Examples of possible variations on these are given later in Sections 3 and 4.

2.1 Problem-based learning

Problem-based learning has been used in medical schools and law schools as early as the 1960s, for example by McMaster Medical School, and with increasing uptake since the 1980s (Knight and Yorke, 2003; Boud and Feletti, 1993; Schwarz et al., 2001). The traditional instructional approach to medical education, consisting of an intensive pre-clinical period of basic science lectures followed by a clinical teaching programme, has been criticised for failing to equip doctors with all the skills they needed and for not providing students with the
context of how their knowledge should be applied \cite{Lancaster Medical School, 2016}.

In the UK the General Medical Council set the requirements for how medical students should be trained. They advocate PBL for the following reasons \cite{Lancaster Medical School, 2016, Savery, 2006}:

- students must have responsibility for their own learning, since learning is most effective when it is active;
- problem scenarios facing students should be complex, since real-world medical problems are rarely straightforward;
- learning should be integrated from a wide range of disciplines and subject areas;
- learning should integrate collaboration, since clinical practice demands that doctors share information and work constructively with others;
- students should share with their work groups what they have learned and how that contributes to the solution of the problem;
- a summary analysis of what has been learned should be undertaken because reflection and evaluation are critical;
- self and peer assessment should be regularly undertaken.

PBL aims to teach students to identify problems and then to design a set of objectives, the accomplishment of which will lead to the development of the solution. Medicine isn’t the only area to widely use PBL: law is the other main area which has adopted this strategy at scale. \cite{Schwarz et al, 2001} points out that the challenges faced by a law school have similarities and differences with those faced by a medical school. It is not unreasonable to assume that the same is true in statistics training: many of the aspects listed above apply directly to statistics education, with the others requiring only minor modifications in language.

### 2.1.1 Group formation and nature of problems

In contrast to the traditional lecture courses common in Higher Education, students are randomly assigned to small groups (typically between 6 and 10 students, though groups are changed every few weeks) to work on an open-ended problem, often called scenarios.

Within a PBL group there are specific roles. Each member of the group is expected to perform each role at least once per term. The roles are as follows:

- Chair – to move the group through the stages of PBL in a timely manner, to ensure coverage of a topic, and to encourage all of the group to participate.
• Scribe – listens and records information (often on a whiteboard), writes up the agreed objectives, and contributes to discussions.

• Other group members – contribute to discussions, articulate knowledge, identify strengths and weaknesses in the group’s knowledge.

2.1.2 Format of PBL sessions

The groups meet to discuss the problem, along with a tutor who acts as a facilitator by asking questions and prompts to guide discussions towards the learning outcomes. With each new scenario the students rotate through the different roles (chair person, scribe, group member), which gives them the chance to develop new skills.

During the first group meeting, students identify what parts of their knowledge are lacking in tackling the problem. They then set their own goals in terms of what information they require in order to solve the problem in hand. Each member of the group researches the required information. The group then reconvenes to discuss what they learnt from their self-study, and apply their new knowledge to the problem in hand. There will typically be several days between the first session and the second session.

2.1.3 Assessment

Each PBL session is evaluated through surveys in which the students reflect on their learning experiences. Final assessment can take any form, and need not be reliant on the group-work during PBL.

2.2 Team-based learning

2.2.1 Team formation and nature of problems

Similarly to PBL, the fundamental idea of TBL is that students work on professionally relevant problems - those that are similar to what they might encounter in the workplace - but the execution of the learning differs from that of PBL. It is now popular in Nursing and Medical schools (Liu and Beaujean, 2017). The teams are formed of between five and seven students, but are not randomly allocated. Instead, the instructor carefully creates groups to ensure that they are heterogeneous, for example, in terms of ability or previous experience. Students do not change groups during the course.
2.2.2 Format of TBL sessions

Before the session Prior to the teams meeting to discuss the allocated problem, each student must prepare for the group work by studying the provided materials. This could be in the form of reading, watching videos, or any other activity that prepares students sufficiently for the task ahead.

During the session – readiness assurance The Readiness Assurance Process (RAP) aims to ensure that all students have the pre-requisite knowledge of the course material self-studied, in order to take part in the later problem solving exercise.

Each student completes an individual test (individual Readiness Assurance Test, or iRAT), designed to highlight any deficiencies in the student’s understanding of the pre-class material. These tests are typically quick-fire multiple choice tests, done using electronic voting equipment so that they are marked instantaneously.

Once completed, students re-take the test, but this time in their allocated groups (team Readiness Assurance Test, or tRAT). Discussion of the questions among team members is encouraged, so that the tRAT itself becomes a learning tool where students learn from each other.

Results are available immediately after the tRAT, allowing students to assess their understanding, but also to contest the questions and/or answers. Teams provide written justification as to why they think they deserve a higher mark, with evidence, e.g. from course material, for the instructor to consider. If the instructor finds in favour of the team, additional marks are awarded. However, only teams who contest will be eligible for additional marks, even if the problem detected was common for all groups. This encourages students to question the material, and also helps in team cohesion.

During the session – lecture Finally, a lecture component gives the instructor opportunity to clarify misunderstandings and common conceptual errors which were picked up during the iRAT and tRAT.

During the session – working on a problem Remaining time is spent on solving a problem using the material learnt. The problems are aimed at testing students’ deeper understanding of the course material, while the RAP process tests base knowledge (Liu and Beaujean, 2017). Such problems generally satisfy four criteria (commonly known as the “4S”):

• the problem must be Significant;
• the teams have a Specific set of possible answers from which they choose one;
• each team works on the Same problem;
teams must Simultaneously report their final answer. Importantly, the problem must not be easily segmented into smaller parts that different team members can tackle: the idea is that the group works together on the whole problem.

2.2.3 Assessment

Assessment for the course is generally a combination of individual tests (iRAT scores and final exam mark), and groupwork mark (tRAT scores, scores from the problem and peer evaluations). Further summative assessment can take any format.

3 Evidence of effectiveness

Among their recommendations, the GAISE College Report suggests that modern Statistics education should teach statistical thinking as an investigative process of problem solving and decision making, should integrate real data with a context and purpose, and foster active learning (Carver et al., 2016). All these attributes are fundamental to both problem- and team-based learning.

The general approach of group-based learning aligns with the constructivist philosophy of learning, where students actively construct their own knowledge rather than passively receiving it (Garfield, 1993). Not only do students learn the subject matter in this way, but they develop softer skills in problem solving that captures some of the non-formal learning that happens in the workplace (Eraut, 2000).

Group-based learning is posited as a largely positive strategy for teaching non-specialist students. Though we found no published literature on the effectiveness of such strategies in teaching Statistics to specialist students (i.e. those pursuing degrees in the mathematical sciences), group-based learning has been successfully implemented for mathematics students in discrete mathematics (Paterson and Sneddon, 2011).

While how we should measure effectiveness in teaching is a source of debate, the evidence relating to group-based learning tend to fall into three categories:

- performance on end-of-module assessments or similar;
- long-term retention of information;
- student enjoyment or engagement with the material.

We discuss the findings of other studies in implementing variants of TBL or PBL in each of these categories.
3.1 Performance on end-of-module assessments

There is some evidence that students perform better on Statistics assessments after completing their course using PBL-type learning as opposed to traditional lectures (Karpiak, 2011). However, it is not clear whether this is genuinely due to better understanding of the course material or some other factors (Giibels et al., 2005; Karpiak, 2011). For non-statistics major courses in particular, the use of PBL may be helpful because it generates a constant use for the statistical methodology, and hence provides students with a motivation to learn (Jaki and Autin, 2009). However, better performance on module assessments could also be a consequence of students engaged in active learning as opposed to learning passively, rather than the effect of the PBL itself, or unwittingly increasing the amount of guidance from PBL tutors to students (Budé et al., 2009).

Improved grades on end-of-module tests was also observed for TBL for service-type courses mathematics (Nanes, 2014) and specifically in Statistics (Liu and Beaujean, 2017; Haidet et al., 2014).

3.2 Long-term retention of knowledge

While there is a growing body of evidence to suggest various group-based learning methods improve end-of-module assessments, far fewer studies have looked at the long-term impact of these strategies on knowledge retention.

We found no studies looking at long-term retention of knowledge and skills in Statistics, and only one in teaching medical students (Emke et al., 2016). In this study, which looked at short- and long-term retention of knowledge and compared a cohort of students taught via TBL with a cohort that was traditionally taught, there was some evidence that the TBL group performed better on assessments in the short-term but no evidence that they retained more knowledge longer term.

3.3 Student enjoyment and engagement

A large body of evidence in the literature points to group-based learning as being a positive experience for students. That this is an aspect that receives most attention is not surprising given the difficulties in comparing understanding of course material between cohorts.

Students are generally positive about TBL in mathematics (Nanes, 2014; Krogstie et al., 2018) and in Statistics (Clair and Chihara, 2012). In particular, some reported students finding mathematical ideas more accessible when the material was taught as a TBL class as opposed to traditional lectures (Paterson et al., 2013). Balancing this overwhelming positivity are some interesting student insights.
from other studies. Naturally, not all students will enjoy an active group-learning environment (Haidet et al., 2014), but more specifically a group environment can encourage some students to ‘coast’ in TBL maths classes, relying on their team-mates for back-up (Paterson et al., 2013). Others - perhaps weaker students - may find the team environment intimidating (Clair and Chihaia, 2012). In the latter case however, team-working and communication is an essential skill which should be developed alongside mathematical or statistical skills (Nanes, 2014; Tinungki, 2015).

Though most of the research we found on student engagement was based on TBL, aspects of problem-based learning for large cohorts have been considered. Klegeris and Hurren (2011) found that PBL sessions for a pharmaceutical course increased attendance in comparison to traditional lectures. This was trialed with and without student additional marks for attendance. They found that offering such a reward for attendance did not significantly affect attendance rates. For large Statistics classes in particular, Budé et al. (2009) found that more guidance from tutors/facilitators during the session resulted in better student perception of the course. They warn that increasing the amount of guidance from tutors in a PBL setting could inadvertently lead students to become passive about their learning and less motivated, though they did not find evidence of this in their study.

4 Problem- and team-based learning of Statistics in practice

Statistics is perhaps an obvious candidate for group-based learning, rich with opportunities in tackling ‘real’ problems and can easily be framed as a believable and relevant problem for either team- or problem-based learning strategies. It is therefore not surprising that PBL for example has been used in Statistics courses for over 20 years (Hillmer, 1996; Boyle, 1999).

Unlike other disciplines perhaps, Statistics is rather dependent on the order that the material is introduced. Its highly structured and sometimes abstract nature makes teaching Statistics via group-based learning a challenge: deficiencies in understanding of basic concepts may cause difficulties in understanding more complex procedures (Bland, 2004; Budé et al., 2009). Students can’t front-load a large amount of information so adaptations may be necessary. Nanes (2014) for example, in teaching a course on linear algebra via TBL, suggests increasing the amount of testing and making the real world problems shorter though care must be taken not to ‘teach to the test’. It is not unreasonable to assume that the same issue could arise in teaching Statistics in this manner.

Implementing group-based learning in Statistics therefore needs careful consideration, and in some cases modifications may be necessary. In this section we
review the major components of this group-based learning and give advice on practical solutions to potential issues.

4.1 The real-world problems

Problems for group-based learning can take any format, though will be different in nature for PBL and TBL. In TBL, students are required to complete pre-reading for the session, when technical information can be conveyed which is relevant in solving the problem. In this way, common procedures such as hypothesis testing and statistical modelling can be taught. Contrast this with PBL: it is probably unrealistic to expect students to tackle data-driven problems solely through PBL (Bland, 2004). For example, expecting students to come to the conclusion that a t-test is appropriate without some prior knowledge is unreasonable, though introducing these concepts in other ways is possible. Here we discuss alternatives to data-driven real-world problems, and their suitability for both TBL and PBL.

Real-world problems that are not data-driven may be easier to implement in class, especially if computing power is not required. They may also be more motivating for students, especially if their studies are outside of the mathematical sciences, if they incorporate more than just the practical data analysis aspects of Statistics. This also alleviates some of the difficulties in obtaining real, relevant, and well structured data for teaching purposes. In Appendix A we provide an outline of a PBL session with an epidemiological focus to demonstrate the type of real-world problem, in this case the issue of measuring student mental health, which could be devised without requiring a dataset.

Alternatives to data driven problems could be of the form of a research paper or similar (Bland, 2004). Asking students to read, digest and report back on findings from a research paper - especially if it is of direct interest to the students - would broaden the scope of Statistics education, taking the emphasis away from mechanical details to interpretation of results, and also motivating students to see the power of Statistics in their own discipline. This strategy in particular is suitable for both PBL and TBL. In PBL, the task could be phrased around understanding the statistical methods employed in a paper and why they were used. In TBL, students could critically appraise the use of techniques in context and suggest alternative ways of addressing the paper’s research questions and/or put forward a different analysis plan for the data collected.

In the same vein, students could be asked to provide advice on a consultancy basis either on the design of an experiment or on the analysis of previously-collected data. For the latter, carrying out the data analysis could be set as a task outside the class (in the case of PBL, for example, before the next group meeting), or even as pre-work in TBL before the next session. Results of which could then be used as a springboard for the following workshop either in terms of discussing output or applying the results to a connected problem.
Whatever the format of a real-world problem, Garfield (1993) emphasises that the hallmarks of good group activities include that all students contribute to the task in hand, and suggest that this could be done by simply emphasising this. Both PBL and TBL benefit from having problems to solve that cannot be split into smaller sub-problems to be tackled individually.

4.2 Teaching space

Any form of group-based learning benefits from suitable classroom-like teaching space where students can comfortably work in groups. Traditionally for PBL, this requires sourcing a suitable room for each group and having access to learning spaces conducive to group work has been found to improve session outcomes (Schwarz et al., 2001; Jones, 1988). This is often too complex to manage, especially with ever increasing class sizes in statistics, with the only viable alternative to host sessions in large lecture theatres (Nicoll and Lou, 2012; Klegeris and Hurren, 2011; Roberts et al., 2005). With some organisation, however, running PBL in these spaces is not insurmountable.

TBL, by its very nature, isn’t hampered by such space constraints and is designed to work in lecture theatres. However, Espey (2008) found that student attitudes toward team-based learning improved with when students perceived the environment they were in to be a comfortable space in which to work in their teams.

Nicoll and Lou (2012) suggests using a classroom that is larger than you need for your group size, to create a more comfortable environment for students, and to allow the instructor easy access to each group. Of course, computer labs may be required for problems requiring a data-driven solution. Cluster rooms are often easier to set up for groups to work together in the sense that they allow some flexibility in set-up in rearranging seating easily to suit each team. It may be better for group cohesion if students are not allocated a PC each; one PC per team goes some way to ensure that the students in a group interact with one another rather than each student ‘doing their own thing’.

4.3 Staff resources

Traditional PBL is staff-intensive, requiring a tutor or facilitator for each group. This is unlikely to be an option for many courses, especially as classes in Statistics are rapidly increasing in size. Though TBL may seem more practical as it does not require a facilitator for each group, some institutions have been successful in running PBL sessions with only one facilitator for the entire class. Researchers found that running PBL alongside traditional lectures in biochemistry and physiology, without having a dedicated tutor for each group, was successful in terms of improving problem solving skills as well as student satisfaction and motivation (Klegeris and Hurren, 2011). Nicoll and Lou (2012) suggest using
on-line platforms such as Poll Everywhere or Twitter so that students can send
questions to the lone instructor, who in turn can either project answers for the
whole class to see or initiate a class discussion. Without a tutor for each group,
however, students need to have some background knowledge of the topic under
consideration (Nicoll and Lou, 2012).

In contrast, Roberts et al. (2005) compares traditional PBL for undergraduate
medics with a modification where students tackle PBL-like tasks without a ded-
icated group tutor. They conclude that the modification is a useful alternative
when insufficient staff resources are available. They do find, however, that stu-
dents with a dedicated facilitator are more likely to perceive the learning activity
as being superior though no difference was detected between the two groups in
terms of achievement.

4.4 Creation of groups and student engagement

Students in the mathematical sciences rarely have the opportunity to interact
and work collaboratively on projects, or to learn from one another. Teaching
is often in traditional lectures while assignments and assessments are often in-
dividual. This is at odds with the nature of mathematics at research level: a
fundamentally collaborative endeavour. Those from outside the discipline may
or may not have worked in groups before. Students’ experience of this way of
working needs to be taken into account at the start of any course using group-
based learning.

Like any new intervention, it may take time for students to get used to the idea
of working in groups. There is evidence that students are more engaged with
the process once they get used to it, so doing this every now and again may not
show the real potential of team-based learning.

In the first instance, explaining the structure of each session, making clear how
groups are expected to work together, what is expected from students, how to
access help, the role of any facilitators, and general code of conduct, should
be the first priority; this is especially so for implementations in large classes
(Roberts et al., 2005). In particular, students who have little or no experience
with small-group learning strategies like PBL or TBL will need more support,
and all sources of help need to be highlighted. All groups need to feel that
they understand the task in hand, feel confident that they can speak to a tutor
when they need guidance, and that they have sufficient resources. For the latter
in particular, this may mean suitable written and/or videoed material. It has
been suggested that recording any lecture components of courses - which occur
in both PBL and TBL - benefits students (Jaki, 2009; Jaki and Autin, 2009).

Course leaders must be prepared for initial student resistance, especially if stu-
dents’ other courses are taught traditionally. Some students may see group-
based learning as a glorified version of self-study (in which case, why pay for
an education?) while others may worry that their marks will be unfavourably
influenced if having to rely on teammates. Responses to such criticisms and concerns could for example include the pedagogical reasons for teaching Statistics in a group-based learning environment, or the benefit in terms of development in terms of soft skills valued by employers. Students worried that their grades may be unfavourably influenced may be placated if they are reassured of the procedures in place to ensure that marks are allocated fairly. There is a body of evidence to suggest that even the strongest students benefit from group-based learning: strong students in groups that work well (e.g. where students are invested in the group’s achievement), tend to do even better as they benefit from thinking about concepts at a deeper level in order to explain them to weaker members of the group. There are also opportunities for students to assess each other. Strategies such as group members having to assess and provide feedback to each other can help students feel that contribution is rewarded while coasting in the group has negative consequences.

How groups are formed can influence the success of a group-based learning course: these learning strategies work only when students engage, and if students are inexperienced in group working then this needs to be monitored and managed carefully. In their original format, both PBL and TBL groups are chosen by the course leader and these groups remain together for more than one session to encourage cohesion and ensure diversity of groups. It may be tempting to allow students to choose their own groups for a number of reasons, including making students feel more comfortable, potentially decreasing student resistance, and ease of administration. In addition, allowing for changing teams in each session may also be tempting, especially if students are not required to attend lecture sessions making steady teams difficult to manage.

However, students do not benefit from working in diverse groups, and possibly suffer from unbalanced groups in terms of ability and skills. Students who are resistant to group-work may feel more obligation to join their allocated group than if asked to find their own group, especially if they don’t have an immediate friendship group in class. The latter group in particular may be severely disadvantaged when students are permitted to choose their own group: joining either a group of students who already know each other may result in problems with group attachment, while creating extra groups consisting of these students may lead to feelings of resentment.

A half-way house is to involve students in the formation of groups in the sense that they decide on how the groups are chosen (even though this is done by the course leader). For example involving students in decisions around the composition of groups: should they be randomly assigned, how long should groups work together for, should groups be mixed in terms of achievement in previous courses, should groups be balanced in terms of academic background of students, should groups be balanced in terms of gender or any other characteristic? Students who feel that they have some say over how their education is managed are more likely to engage in the first place.
4.5 Staff reaction

There is evidence to suggest that lecturers find the use of group-based learning a satisfying experience (Jones, 1988), and it is reasonable to think that this is because the process is a more interactive experience than didactic teaching. Through this interaction the course leader may naturally find that they have a better understanding of a student’s strengths and weaknesses, enabling them to address these issues directly.

When making the transition to group-based learning Boud and Feletti (1997) and Schwarz et al. (2001) found that introducing students and faculty members into the new curriculum, as opposed to simply starting it without introductory sessions, helped in its successful adoption.

5 Discussion

The importance of quality of teaching in the UK Higher Education sector is emphasised by the introduction of the Teaching Excellence and Student Outcomes Framework (TEF, Office for Students 2018) to sit alongside the Research Excellence Framework (REF). The first TEF awards were assigned in 2018, and were evaluated for each University as a whole. The second round of TEF awards, planned for 2021, will include subject/departmental specific assessment. Universities are encouraging teaching staff to modernise their teaching, with focus on the TEF but also the National Student Survey results.

There is mounting evidence that traditional lecture courses are not as effective as ‘active’-type learning strategies in Science, Technology, Engineering, and Mathematics (STEM) subjects (Freeman et al., 2014), and indeed specific evidence that PBL and TBL - as active learning methods - are effective. Bland (2004) goes as far as saying that not using such methods (PBL in this specific case) for statistics and research methods training is detrimental to students, while Tinungki (2015) highlights the importance of communication in learning mathematics which is well addressed in group-based learning. Indeed, both PBL and TBL are ideally placed to meet the needs of employers, who have often identified poor team working skills, poor written communication skills, and poor oral presentation skills in graduates (Knight and Yorke, 2003).

There has been an explosion of technological advances since Gelman and Nolan (2002) outlined approaches for teaching Statistics. In the modern teaching environment both teachers and students are surrounded by resources which weren’t previously available. From a student’s perspective getting information has never been so easy, speeding up tasks such as the research component in PBL. From a teacher’s perspective, numerous platforms (listed in Appendix B) make learning and interaction with a class more manageable, whilst student monitoring becomes ever easier with tracking via virtual learning environments or auto-
mated marking of online quizzes. These factors contribute to the success of group-based learning strategies.

However, while for Statistics modules where there is an applied component there is clear scope to apply group-based learning for the whole or at least part of the module, it is not clear how, or even whether, such learning strategies are suitable for Statistics modules which are of a more mathematical nature. In the first instance, the technical nature may make it difficult to create a truly ‘real-world’ problem, and this was also noted by Nanes (2014). Secondly, highly mathematical modules generally rely more heavily on students’ prior knowledge. For students whose prior knowledge isn’t strong, personality and motivation is likely to play a large part in their success on the module: a group-based learning module could be intimidating, or the group environment may be the key to success.

Paterson et al. (2013) note that few mathematics lecturers use a group-based learning approach to their teaching. One possible reason for this is that rewriting existing courses to entirely group-based learning modules in one fell swoop may not be practical. It needn’t be all-or-nothing, however. Introducing students to group-based learning slowly may be beneficial (Bond and Feletti, 1997; Schwarz et al., 2001). Elements of group-based learning could be woven through modules, for example particular topics within a module could be taught in a group-based setting, or even just particular sessions. Care needs to be taken, however, in ensuring that students know why you are doing this, and how it benefits them, otherwise the risk is that students won’t engage.

Using group-based learning needn’t mean using only PBL, or only TBL, however. Some educators have experimented with combining parts of PBL and TBL to maximise the benefits to students. For example, combining the peer feedback (TBL) with an initial group discussion before the pre-reading assignments (PBL), are possibly positive enhancements to any group learning strategy (Dolmans et al., 2017). Online variants of PBL have also been trialled successfully (de Jong et al., 2013). That modifications to the traditional PBL and TBL methods have been successful shows that these strategies are ripe for shaping to fit both the practical constraints of the course, as well as the course content.

We have shown that implementation of PBL, TBL, or a variant thereof, is possible in the teaching of applied statistics. However group-based learning is implemented, the emphasis on a more rounded student education is clear. Of course, these are not the only active learning strategies. Which is the most effective is the subject of its own debate, and students with different learning styles may prefer different teaching methods (Bloom et al., 1956), but there is good evidence for group-based learning in statistics.
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References

J. M. Bland. Teaching statistics to medical students using problem-based learning: the australian experience. *BMC Medical Education*, 4(34), 2004.

B. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl. *Taxonomy of educational objectives: Handbook I: Cognitive domain*. David McKay Company, New York, US, 1956.

D. Boud and G. Feletti. *The challenge of problem-based learning*. Kogan Page, London, UK, 1997.

C. R. Boyle. A problem-based learning approach to teaching biostatistics. *Journal of Statistics Education*, 7(1), 1999.
L. Budé, T. Imbos, M. W. J. v. d. Wiel, N. J. Broers, and M. P. F. Berger. The effect of directive tutor guidance in problem-based learning of statistics on students' perceptions and achievement. *Higher Education*, 57(1):23–36, Jan 2009.

R. Carver, M. Everson, J. Gabrosek, N. Horton, R. Lock, M. Mocko, A. Rossman, G. H. Rowell, P. Velleman, J. Witmer, and B. Wood. Guidelines for Assessment and Instruction in Statistics Education (GAISE) College Report. Technical report, American Statistical Association, 2016. URL https://www.amstat.org/ASA/Education/Guidelines-for-Assessment-and-Instruction-in-Statistics-Education-Reports.aspx. Accessed 2019-08-12.

K. S. Clair and L. Chihara. Team-based learning in a statistical literacy class. *Journal of Statistics Education*, 20(1), 2012.

N. de Jong, D. M. L. Verstegen, F. E. S. Tan, and S. J. O’Connor. A comparison of classroom and online asynchronous problem-based learning for students undertaking statistics training as part of a public health masters degree. *Advances in Health Sciences Education*, 18:245–264, 2013.

D. Dolmans, L. Michaelsen, J. van Merriënober, and C. van der Vleuten. Should we choose between problem-based learning and team-based learning? No, combine the best of both worlds! *Medical Teacher*, 37(4):354–359, 2015.

A. R. Emke, A. C. Butler, and D. P. Larsen. Effects of team-based learning on short-term and long-term retention of factual knowledge. *Medical Teacher*, 38(3):306–311, 2016.

M. Eraut. Non-formal learning and tacit knowledge in professional work. *British Journal of Educational Psychology*, 70:113–136, 2000.

M. Espey. Does Space Matter? Classroom Design and Team-Based Learning. *Applied Economic Perspectives and Policy*, 30(4):764–775, 01 2008. ISSN 2040-5790. doi: 10.1111/j.1467-9353.2008.00445.x. URL https://doi.org/10.1111/j.1467-9353.2008.00445.x

S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. Active learning increases student performance in science, engineering, and mathematics. *PNAS Proceedings of the National Academy of Sciences of the United States of America*, 111(23):8410–8415, 2014. ISSN 0027-8424. doi: 10.1073/pnas.1319030111.

J. Garfield. Teaching statistics using small-group cooperative learning. *Journal of Statistics Education*, 1(1), 1993. doi: 10.1080/10691898.1993.11910455.

A. Gelman and D. Nolan. *Teaching Statistics: A bag of tricks*. Oxford University Press, New York, US, 2002.
D. Gijbels, F. Dochy, P. V. den Bossche, and M. Segers. Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of Educational Research*, 75(1):27–61, 2005.

P. Haidet, K. Kubitz, and W. McCormack. Analysis of the Team-Based Learning Literature: TBL Comes of Age. *Journal on Excellence in College Teaching*, 25:303–333, 2014.

S. C. Hillmer. A problem-solving approach to teaching business statistics. *The American Statistician*, 50:249–256, 1996.

T. Jaki. Recording lectures as a service in a service course. *Journal of Statistics Education*, 17(3):1–13, 2009. ISSN 10691898.

T. Jaki and M. Autin. Using a problem-based approach to teach statistics to postgraduate science students: A case study. *MSOR Connections*, 9(2):40–47, 2009.

K. Jones. *Interactive learning: A guide for facilitators*. Kogan Page, London, 1988.

C. P. Karpiak. Assessment of Problem-Based Learning in the Undergraduate Statistics Course. *Teaching of Psychology*, 38(4):251–254, 2011.

A. Klegeris and H. Hurren. Impact of problem-based learning in a large classroom setting: student perception and problem-solving skills. *Advances in Physiology Education*, 35(4):408–415, 2011. doi: 10.1152/advan.00046.2011.

P. T. Knight and M. Yorke. *Assessment, Learning and Employability*. Open University Press, Maidenhead, UK, 2003.

B. Krogstie, K. Berntsen, and A. Wrålsen. Adapting team-based learning in a mathematics course for computer engineering students. *Proceedings from the annual NOKOBIT conference held at Svalbard the 18th–20th of September 2018*, 26(1), 2018.

Lancaster Medical School. Problem-Based Learning Handbook Study Guide: Tutor Version. Lancaster University Medical School Study Guide, 2016.

S. Liu and A. Beaujean. The effectiveness of team-based learning on academic outcomes: A meta-analysis. *Scholarship of Teaching and Learning in Psychology*, 3(1):1–14, 2017.

T. Mann. Law student becomes sixth to ‘commit suicide’ in Bristol this year, May 2017. URL [https://bit.ly/2mq2VqI](https://bit.ly/2mq2VqI) Accessed 2019-09-19.

K. M. Nanes. A modified approach to team-based learning in linear algebra courses. *International Journal of Mathematical Education in Science and Technology*, 45(8):1208–1219, 2014.
T. A. Nicoll and K. Lou. A model for small-group problem-based learning in a large class facilitated by one instructor. *American Journal of Pharmaceutical Education, 76*(6):117, 2012.

Office for Students. What is the TEF?, 2018. URL https://www.officeforstudents.org.uk/advice-and-guidance/teaching/what-is-the-tef/. Accessed 2019-08-12.

J. Paterson and J. Sneddon. Conversations about curriculum change: mathematical thinking and team-based learning in a discrete mathematics course. *International Journal of Mathematical Education in Science and Technology, 42*(7):879–889, 2011.

J. Paterson, L. Sheryn, and J. Sneddon. Student responses to team-based learning in tertiary mathematics courses. *Proceedings of 15th Annual Conference on Research in Undergraduate Mathematics Education, 2*: 619–626, 2013.

C. Roberts, M. Lawson, D. Newble, A. Self, and P. Chan. The introduction of large class problem-based learning into an undergraduate medical curriculum: an evaluation. *Medical Teacher, 27*(6):527–533, 2005. doi: 10.1080/01421590500136352.

C. J. Roseth, J. B. Garfield, and D. Ben-Zvi. Collaboration in learning and teaching statistics. *Journal of Statistics Education, 16*(1), 2008. doi: 10.1080/10691898.2008.11889557.

R. J. Savery. Overview of problem-based learning: definitions and distinctions. *Interdisciplinary Journal of problem-based learning, 1*(1):9–20, 2006.

B. Schloerke, J. Allaire, and B. Borges. *learnr: Interactive Tutorials for R*, 2018. URL https://CRAN.R-project.org/package=learnr. R package version 0.9.2.1.

P. Schwarz, S. Mennin, and G. Webb, editors. *Problem-based learning: case studies, experience and practice*. Routledge, London, UK, 2001.

G. M. Tinungki. The role of cooperative learning type team assisted individualization to improve the students’ mathematics communication ability in the subject of probability theory. *Journal of Education and Practice, 6*(32):27–31, 2015.
A Example Statistics PBL session: Student mental health – is there a crisis?

A.1 Scenario

Consider the scenario in which you are working as a statistician in the civil service in the Department for Education. Recently there have been several cases of students committing suicide. For example, six students committed suicide in the 2016/2017 academic year in Bristol [Mann, 2017].

Ministers want to know if there really is a crisis in terms of the number of students suffering from mental health problems. You are tasked with investigating this issue.

One minister has read some epidemiological research and is curious as to whether this year’s cases are reflective of a truly increasing trend in mental health cases or whether this increase is an anomalous spike in the data.

You are tasked with preparing a short structured report (no more than 5 pages) and presentation on this question.

One issue to consider is that there is limited extra government funding for your analysis: you are not be able to carry out a new study to investigate the issue. Therefore, you should address how you can overcome this limitation.

A.2 Indicative learning objectives

Statistical methods:

- research how to estimate different measures of association;
- investigate time series methods.

Applied Statistics:

- research epidemiological concepts such as incidence and prevalence;
- understand the differences between different absolute and relative measures of association such as the risk difference and the risk ratio. Consider which measures might be more informative for public health policy makers.

Statistical programming:

- demonstrate how to access publicly available datasets and prepare these for analysis using a software of your choice;
- show how to present complex longitudinal analyses graphically.
B Helpful apps, websites, and technologies

• General advice:
  – Collaboration of TBL practitioners (the Team Based Learning Collaborative) which makes example teaching material available online [http://www.teambasedlearning.org/].

• Online polls and quizzes:
  – Sli.do [https://www.sli.do/] website to create audience polls;
  – Kahoot [https://kahoot.it] website to create and run online quizzes;
  – Turning Point: audience response system and polling software [https://www.turningtechnologies.com/turningpoint];
  – Mentimeter [https://www.mentimeter.com] App and website to create interactive presentations.
  – Wooclap [https://www.wooclap.com] create and run online quizzes, real-time discussion boards suitable for classroom use.

• R packages:
  – There is a task view on CRAN on listing R packages helpful for teaching Statistics, [https://CRAN.R-project.org/view=TeachingStatistics].
  – The Bayesian task view also has a section devoted explicitly to teaching Bayesian Statistics [https://CRAN.R-project.org/view=Bayesian].
  – learnr package [https://rstudio.github.io/learnr/] creates R tutorials and quizzes [Schloerke et al., 2018].
  – exams package [http://www.r-exams.org/] allows a user to create quizzes from an R script. The quizzes can be exported in various formats, such as the xml format for a moodle quiz which can be embedded into a moodle page.
  – Shiny runtime [https://shiny.rstudio.com/] produces web applications running R code.

• Notebook formats:
  – R Markdown Notebooks: RStudio [https://rstudio.com] provide the .nb.html format in which the cells are active within an RStudio session. These files can also be viewed in a web browser, at which point the cells are no longer active but can still be viewed.
  – Jupyter (formerly Ipython) notebooks [https://jupyter.org/]. These notebooks allow users to distribute html documents in which the cells
of the notebook execute analyses if the user has the appropriate kernel installed. If the kernel is not installed the cells cannot be executed but the documents can still be viewed in a browser.

- Presentation formats:
  - ioslides
  - Prezi: [https://prezi.com](https://prezi.com)
  - Microsoft Sway: An application to produce interactive reports and presentations. [https://sway.office.com/my](https://sway.office.com/my)
  - \LaTeX Beamer (the German for overhead projector). A popular modern Beamer theme is the Metropolis theme [https://github.com/matze/mtheme](https://github.com/matze/mtheme)