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Approaches to feedback in the mathematical sciences: just what do students really think?

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Assessment and feedback is an area where mathematical sciences departments have invested significant effort in recent times. Particular challenges have been identified relating to timely and detailed feedback, both of which are important given the widespread use of formative, and typically weekly, problem sheet assessments to aid and structure the mathematical development of learners. Here we report on a first cycle of action research, linked to the implementation of a revised curriculum in a large UK research-intensive mathematical sciences department, which was designed to enhance the feedback received by students and their subsequent engagement with it. Whilst we draw upon the results of a survey of 74 undergraduate students, we also describe the pilot of a method for providing video-based marking and feedback. Our results show the importance that students within the mathematical sciences place upon feedback as part of their learning experience, but also that amongst those undergraduates surveyed, there was no clear consensus as to whether they had received sufficient feedback upon their work. The findings reinforce the need for students themselves to engage with their mathematical feedback in a meaningful way, and significantly they indicate that the feedback perceived as most valuable involves opportunities to engage in dialogue about their work with either their peers, postgraduate teaching assistants, or academic members of staff. As such, the emphasis that departments place upon providing 'detailed written comments' on formative work appears not to be valid, and instead more 'dialogical' or 'interactive' mechanisms for providing feedback in mathematics may have the potential to yield more effective results.

Keywords: assessment; feedback; mathematics

1. Introduction

Discussions of assessment in mathematics are often focused upon that of the unseen closed-book examination which is known to dominate current assessment practices. For example, in their 2011 review of undergraduate mathematics assessment, Iannone and Simpson (2011, p4) investigated a total of 1843 modules and noted that *"over one quarter of the modules (535) in the sample are assessed entirely by closed book examination and nearly 70% of the modules (1267) use closed book examinations for at least three quarters of the final mark."* Focusing such a discussion upon the unseen closed-book examination however, belies the importance of a more dominant form of assessment vital to supporting the mathematical development of students: the problem or exercise sheet.

Problem sheets, as we shall choose to refer to them from now on, form a key part of the undergraduate mathematical sciences curriculum with many universities distributing these on a weekly basis and students devoting a significant part of their time outside of core teaching hours working to complete them. The intended purpose of problem sheets is to help students "*understand and appreciate definitions and theorems mentioned in lectures, applying them in what are for students, novel contexts…they most often build on or activate book-work from the course*" (Badger, Sangwin & Hawkes, 2012, p40). Whilst they may have a nominal level of credit associated with them, typically to incentivise their completion and submission, and often contributing towards the overall grade at a module level, their primary purpose is formative which means that the feedback provided can be used to "*shape and improve the student's competence by short-circuiting the randomness and inefficiency of trial-and-error learning*" (Sadler, 1989, p120). In mathematics, if used effectively, problem sheets form a critical mechanism by which learners can help structure and judge their own mathematical development and progress.

Feedback is an essential part of the formative assessment process, providing the student with information about how successfully an activity has been completed. Underpinning this is the role of the teacher who "*knows which skills are to be learned, and who can recognize and describe a fine performance, demonstrate a fine performance, and* *indicate how a poor performance can be improved*" (Sadler, 1989, p120). However, comments by a teacher that highlight the strengths and weaknesses of a piece of work are, by themselves, insufficient. There must be engagement by the student with the feedback to allow them to reflect upon their own learning, identify where, and how, they can improve, and perform an analysis of their own skills and abilities. While there exist a range of studies exploring how students use the feedback they receive (see for example Orsmond & Merry, 2011; Steen-Utheim & Hopfenbeck, 2019), as Winstone et al. (2017, p17) argue "*there is increasing consensus that a critical determinant of feedback effectiveness is the quality of learners' engagement with, and use of, the feedback they receive.*" This has led some (see for example Yorke, 2003) to suggest that in addition to enhancing the quality of feedback provided, teachers should also focus their efforts upon strengthening the self-analysis skills of their students. As Sadler argues, for a student to have an understanding of the standard being aimed for, to be able to compare their own performance with that standard, and then engage in action to close the performance gap, they must "*possess some of the same evaluative skills as their teacher*" (as cited in Nicol & Macfarlane-Dick, 2006, p204).

The role of feedback in the learning process is vital as "*few physical, intellectual or social skills can be acquired satisfactorily simply through being told about them*" (Sadler, 1989, p120). As such, there have been a number of studies exploring the impact of feedback upon the student learning experience across a range of education sectors. In their review article, Black and Wiliam (1998) analysed over 250 studies of formative assessment coupled with feedback and identified that positive benefits were noted across a range of subjects, student abilities and levels of education. Whilst other studies have commented that "*a limited body of scientifically based empirical evidence exists to support that formative assessment directly contributes to positive educational outcomes*", they too have concluded "*the research discussed in the Black and Wiliam's (1998) review and the other research discussed here does provide some support for the impact of formative assessment on student* *achievement*" (Dunn & Mulvenon, 2009, p1,p9).

In a more recent review, Evans (2013, p106) analysed over 450 articles exploring assessment feedback within higher education. This review reinforced that assessment feedback can enhance student performance, but noted caution as this is "*not in every context and not for all students*". Most significantly, the analysis of Evans (2013, p106) highlighted that while "*some principles of effective assessment feedback design have been established, the implementation of such designs has been demonstrably more problematic*". This challenge in implementing effective feedback is not in itself surprising. In the study undertaken by Carless (2006, p230) of written feedback on assignments, a recurring finding was the different perspectives that students hold, when compared to staff members, on elements of the assessment and feedback process, and that "*these perceptions represent a key challenge to enhancing assessment and feedback practices*". As Carless (2006, p220) notes, one possible mechanism for overcoming these differing perceptions is through "'*Assessment dialogues' between tutors and students*". Here, the emphasis is not on discussing either the subject content or what students need to do in order to be successful in a particular assignment, but more on discussing the assessment process as a general concept. This indicates that work to enhance student perceptions of feedback may be better targeted at a programme or module level, rather than on the basis of each individual assignment.

The research evidence (Evans, 2013; Black & Wiliam, 1998) notes the positive impact that feedback can have upon the learning experience, but significantly it is the students themselves who are now able to comment upon the quality, quantity and timeliness of the feedback they receive in a national context. The key mechanism for this is the National Student Survey (NSS), first launched in 2005, which collects feedback, via a survey, from final year undergraduate students in the UK on their experiences of various aspects of their courses. For the 2017 NSS, the structure and wording of the questions were revised, particularly in relation to assessment and feedback. Whilst this does render any attempt to make direct comparisons with previous years invalid, it is interesting to explore the responses in the mathematical sciences in 2011 (Table 1) with those in 2017 (Table 2).

	Mathematics Only	**All Subjects (Excluding Mathematics)**
5. The criteria used in marking have been clear in advance	73.6%	73.1%
6. Assessment arrangements and marking have been fair	84.0%	74.2%
7. Feedback on my work has been prompt	74.0%	62.4%
8. I have received detailed comments on my work	59.4%	67.0%
9. Feedback on my work has helped me clarify things I did not understand	63.4%	61.4%
22. Overall, I am satisfied with the quality of the course.	88.2%	83.0%

Table 1: Percentage of students who indicated they either 'Definitely agree' or 'Mostly agree' with Questions 5 – 9 and 22 within the 2011 National Student Survey (From HEA, 2012). The number of responses range from 236,544 – 259,188 (All Subjects) and 4,278 – 5,137 (Mathematics Only).

	Mathematical Sciences	**All Subjects (Including Mathematical Sciences)**
8. The criteria used in marking have been clear in advance.	74.9%	73.2%
9. Marking and assessment has been fair.	84.4%	73.4%
10. Feedback on my work has been timely.	82.3%	73.2%
11. I have received helpful comments on my work.	74.3%	74.3%
27. Overall, I am satisfied with the quality of the course.	88.7%	84.5%

Table 2: Percentage of students who indicated they either 'Definitely agree' or 'Mostly agree' with Questions 8 – 11 and 27 within the 2017 National Student Survey. (From HEFCE, 2017). The number of responses range from 318,930 – 319,180 (All Subjects) and 5,618 – 5,626 (Mathematical Sciences).

The data in Table 1 are taken directly from a 2012 Higher Education Academy report (HEA, 2012) whereas those in Table 2 have been compiled from data made available by the Higher Education Funding Council for England (HEFCE, 2017). For Table 2, whilst there are limitations in the analysis (for example they were compiled from summary data rather than original data) it is the broad trends that are important. Indeed as noted by Hewson (2011, p28) in his analysis of NSS data, "*the brief findings reported here have to be interpreted with great caution, but they are intriguing*".

Whilst the revised wording of the question itself could be a factor, it is interesting to see that students do seem to be reporting they are now more satisfied with the speed of provision of their feedback. With students themselves now contributing a greater proportion of the costs of their education (up to £9,000 per annum in England from 2012), and with a national move towards more student-focused teaching excellence (DfE, 2017), institutions are increasingly using metrics like the NSS as both a driver, and a measure, of change. There has been significant activity to increase NSS scores within the mathematical sciences in the category of 'Assessment and Feedback', yet, as Table 2 clearly shows, there remains more to be done in providing feedback that students themselves deem to be 'helpful'. In addition, while Small and Attree (2015, p2078) note that students are becoming "*more self-reflective learners using feedback rubrics to compare their assessment with the academic comments...there are still issues of power imbalance as students may still be unwilling to contact academics if the feedback requires clarification.*" As such further work is needed to empower students themselves to better act upon the feedback they receive as part of their own learning experience.

Whilst we describe here an initiative to enhance student feedback, and the subsequent engagement with it by students, this work was not undertaken in isolation. Through the National HE STEM Programme (See Grove, 2013), a project involving over 30 academic staff and approximately 850 students explored feedback practices in the mathematical sciences. The outcomes from this work are described in Robinson (2015). In addition to providing an excellent overview of feedback in the context of the mathematical sciences, it identifies 10 possible aims of feedback, discusses examples of good or innovative practice, and offers helpful suggestions for departments to enhance the feedback they provide.

In his suggestions for enhancing feedback, Robinson (2015) highlights a tension between providing feedback that is detailed and feedback that is timely; a clear distinction noted in the NSS. This tension is not new. Timely feedback was highlighted by Chickering and Gamson (1987) as one of their seven principles of good practice in undergraduate education, with students known to particularly value this timeliness since the work will still be fresh in their minds (Poulos & Mahoney, 2008). However, as Gibbs and Simpson (2005) comment, resource pressures within higher education are resulting in feedback being provided more slowly, and that efforts in providing feedback after a course has ended are likely to be wasted. Gibbs and Simpson (2005, p19) go on to suggest that "*imperfect feedback from a fellow student provided almost immediately may have much more impact than more perfect feedback from a tutor four weeks later*". As such, the work we describe here has sought to address the dual motivation of providing feedback of a sufficient quality and quantity to aid learning, but which is also delivered in a timely manner such that it can influence a student's future performance on problem sheet assessments that may be set only one or two weeks after the previous submission.

Within the mathematical sciences, and indeed other STEM (science, technology, engineering and mathematics) and non-STEM disciplines, many students experience challenges associated with their learning of mathematics as they make the transition to university study. Lawson (2015, p43) provides a comprehensive discussion of these issues and the evidence for them, but factors include the procedural nature of A-level mathematics, a "*lack of mathematical resilience allied to less intrinsic liking of the subject than [they] realised*", and academic staff having "*unrealistic expectations of their students*". Through a series of linked studies, Williams (2015) investigated student trajectories in and through mathematics programmes from school, through college to higher education. In one aspect of the research, students were asked about their feelings regarding their transition from school to university and were also asked to compare their opportunities to ask questions and discuss ideas at university compared with school. These findings led Williams (2015, p28) to conclude "*that negative feelings are generally associated with a perception of poorer dialogue when students enter university programmes, and vice versa*". This was reinforced by subsequent interviews and collected case studies which also noted that students making the transition found their interactions with academic staff were fewer and less engaging than they expected (Williams, 2015).

Such transitional issues are not restricted to the school-university interface. As Croft and Grove (2015) note, there are many independent research studies that report a decrease in the enjoyment and engagement with the subject by specialist mathematics students as their studies progress. Often the students who report these feelings "*are not failing students – indeed many are doing rather well*" (Croft & Grove, 2015, p173). It is particularly interesting to note that in their recommendations for enhancing the second-year experience for such students, all of Croft and Grove's (2015) suggestions involve opportunities for increased interaction and dialogue between students and academic staff further reinforcing the importance of the findings of Williams (2015).

2. Background

The motivation for the work we describe here was to enhance undergraduate feedback in mathematics, but it formed part of a much wider development. During the 2010/11 academic year, a full-scale review of the undergraduate mathematics curriculum was undertaken within a large research-intensive mathematics department within the UK. Whilst a key focus for this was to enhance the graduate skills, employability and career awareness of students, it also provided an opportunity to consider the curriculum structure, assessment arrangements and support opportunities available to learners, particularly during years 1 and

2. Such a broad focus was a deliberate attempt to help address some of the well known and documented challenges experienced by students in transition described earlier in Section 1.

In an attempt to mitigate these challenges for our learners, a series of interventions were established in the immediate academic years following the curriculum review. Their purpose was to enhance student opportunities for formative feedback, a need identified within departmental NSS scores, by enabling increased dialogue about their learning with peers, postgraduate teaching assistants (PGTAs), and academic members of staff.

2.1. The establishment of a tutorial programme

The weekly compulsory tutorial programme introduced in year 1 was intended as a means of helping all single and joint honours mathematics students adjust to the different nature of university study, but also as a mechanism for providing feedback on the weekly formative problem sheets. Students received a problem sheet on a Wednesday, submitted their solutions for marking by PGTAs exactly one week later, with work being returned to learners at the tutorial on either the Thursday or Friday of the following week. As such, the period between submission and return of feedback was a maximum of seven working days. Academic members of staff acted as a tutor to an allocated tutorial group, typically 12 students who they saw for an hour each week in groups of 6, with PGTAs returning student work directly to tutors. Each tutor therefore had an opportunity to review the progress of their tutees before the tutorial and to plan the topics for discussion. The tutorials were student-led, but their purpose was to enable detailed discussion of the problem sheets and the associated mathematical concepts and ideas, and for students to receive further feedback in addition to the comments written by PGTAs on their work and the available worked solutions. In year 2, the format differed slightly as whilst tutorials remained compulsory, assessed problem sheets were returned directly to students, and tutorials alternated between a problem sheet (based around one of the core modules taken by all undergraduates) intended for discussion during the tutorial and professional development activities designed to encourage students to prepare for life after their undergraduate studies.

2.2. Subject-specific training for postgraduate students involved in supporting student learning

Problem sheets are the most dominant method of formative assessment within the mathematical sciences, and typically within the early years of undergraduate programmes they are marked by PGTAs using a mark scheme and worked solutions provided by an academic member of staff. Postgraduates also have an important role in supporting the delivery of workshop-style classes, which in this case were delivered prior to the submission deadline allowing students to discuss the problem sheets and their associated mathematical ideas. Whilst it is typically the case in many departments that PGTAs will receive a level of training before commencing their teaching duties, this is often generic in nature. In an attempt to address some of the student feedback regarding the level of support that they receive with their learning from the PGTAs, we chose to embed a disciplinary model of training, taking place at the start of each academic year, and ongoing support based upon a model that ran nationally for many years (and described in Cox & Kyle, 2005). This training replaced all but a single two-hour module of generic training, and focused upon encouraging and supporting PGTAs to engage in dialogue with students about their mathematical learning. In addition, a further focus of the training was upon marking student work, and in particular establishing expectations within the PGTAs around their provision of feedback.

2.3. A University-wide mathematics support centre and Peer Assisted Study Support (PASS) sessions.

One popular, and evidence-based response to supporting students with their learning of mathematics as they begin their university studies is the mathematics support centre. Croft et al. (2015) provide a detailed discussion of mathematics support and its origins, but a mathematics support centre comprises a physical location, in our case based within the main university library, where students can drop-in at any time during its hours of opening to receive advice on mathematical queries. This is in addition to the support they receive as part of their undergraduate programme. Mathematical support is provided by tutors, and these are postgraduate mathematics students who have identified they wish to work in the centre, possess the skills and abilities to do so (i.e. the recruitment process is selective), and who then receive additional training and mentoring support (see for example Croft & Grove, 2016). Whilst student users may attend in groups, the experience is personal and driven by the individual student; indeed "*one of the key benefits of this approach recognized by students is the ability to engage in individual mathematical dialogue with a tutor about their learning*" (Grove et al., 2019a, p49). From January 2015, the hours of support available in the mathematics support centre during term time were increased from 15 to 30 hours per week. Whilst the centre was established to support learners from all disciplines making the transition to university, in the academic year 2016/17 of the 980 visits made by students, 80% were by mathematics students, and of all visits, almost two-thirds were made by mathematics students in either year 2 or beyond (Grove, Guiry & Croft, 2019b).

A somewhat related Peer Assisted Study Scheme (PASS) initiative was also established within the department. Such schemes (Walker, 2015) recognise that, in many cases, students feel more comfortable asking questions of fellow students. Here students from years 2, 3 and 4 volunteered to act as PASS Leaders and provided up to five hours of mathematical support per week during term time to their fellow students and typically to those in year 1.

2.4. New module developments and video-based feedback

More broadly, through the curriculum review described earlier, there existed a strong desire and rationale within the department for providing increased opportunities for students to develop the skills of mathematical modelling and problem solving (Savage & Grove, 2015) coupled with developing their wider employability skills and careers awareness (Waldock & Hibberd, 2015). Two new modules, compulsory for all single honours (specialist) mathematics students, were established: Mathematical Modelling and Problem Solving (Year 1) and Mathematics in Industry (Year 2). Whilst we choose not to discuss these in detail here, they possess a number of features highly relevant to our work on feedback. Both modules focus upon students completing authentic modelling and problem solving tasks in a workshop-style environment, but doing so as part of a team, and producing their findings in a variety of different formats. In addition to the extensive peer-peer dialogue this approach fosters, a large amount of personalised support is available from the module lecturer (within and outside of the sessions) and from postgraduate teaching assistants acting as advisors to a small number of groups with whom they worked closely throughout the formal sessions. Most significantly, as both modules are assessed completely through in-course assessment, it was possible to naturally embed new approaches to providing feedback on the summative tasks, particularly as this feedback could then be used by the student to inform their subsequent submissions.

With financial support from the University, video-based feedback was embedded within both modules to explore whether students felt this enabled them to receive more detailed feedback upon their submitted mathematical work. In this approach, students uploaded their work directly to the virtual learning environment (VLE), and PGTA markers captured the computer screen as they annotated student work and provided an accompanying audio commentary. This video-based feedback, on either an individual or group submission, was then returned to students via a video link uploaded to the VLE. The financial support also enabled video-based feedback to be trialled with the in-course (formative) tasks of a year 3 module, and for a small-scale pilot of using this approach with year 1 weekly problem sheets. It also allowed two student interns to be employed for approximately eight weeks during the summers of 2014 and 2015. The interns worked on a range of activities, including gathering student perspectives of feedback, but most significantly they trialled and evaluated several approaches to providing audio and video-based feedback, along with producing staff and student guides on providing feedback (Collis & Sivantharajah, 2014a) and utilising feedback (Collis & Sivantharajah, 2014b). This latter guide includes an interactive activity now embedded in the tutorial programme to allow students to better understand the purposes of feedback and the feedback they receive, and to begin to develop their skills to then use this more effectively in support of their own mathematical development.

3. Research methodology

When seeking to explore the impact of a change in practice, an appropriate methodology is one of action research. Cohen, Manion and Morrison (2000) provide a comprehensive overview of action research and its origins as a means of enquiry, but a key underlying principle noted by Kemmis and McTaggart (1992) is that it forms an approach to improving education by changing it and through learning from the consequences of those changes. While Kemmis and McTaggart (1992) distinguish action research from the practice of teaching, there exists a close connection between the two as noted by Zeni (1998, p208): "*Action research involves practitioners studying their own professional practice and framing their own questions. Their research has the immediate goal to assess, develop or improve their practice. Such research activities belong to the daily process of good teaching. . .*" It is this close connection between 'action' and 'research' that not only makes action research unique, but also attractive to practitioners, and most significantly accessible to those who may be new to the whole process of educational enquiry. Indeed in the action research based approach to educational enquiry in mathematics described by Grove & Kyle (2014), a direct analogy is made with the approach to disciplinary research in the mathematical sciences.

Action research develops through a "*self-reflective spiral*" and consists of a spiral of cycles involving: "*planning, acting (implementing plans), observing (systematically), reflecting...and then replanning, further implementation, observing and reflecting*" (McTaggart, 1997, p34). It may be represented diagrammatically as shown within Figure 1 which has been developed to demonstrate the action research cycle implemented here.

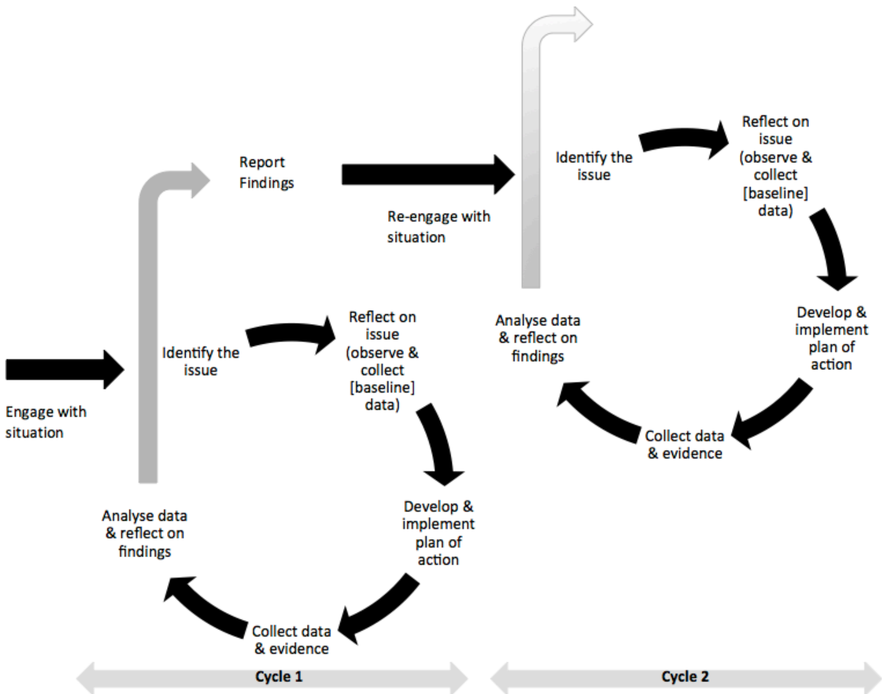

Figure 1: The Action Research Spiral.

Described here are the results from the first cycle of action research. Whilst some initial data were collected through the student internship programme (Collis & Sivantharajah, 2014a), this was not intended to provide a formal baseline, but more context to inform the development of a staff handbook. Nevertheless, their results are interesting as they highlight that almost 40% of the students they surveyed rated their feedback as either average or poor (as we shall see this is in line with our own findings) thereby validating the need for both an intervention and further study.

In Summer 2016 an online survey consisting of 17 questions (listed in Appendix 1) was undertaken, and aimed at single and joint honours students (n~800) from all four years studying for an undergraduate mathematics degree with a view to capturing their views on the feedback they had received as part of their studies and as a means of exploring the impact of the curriculum review changes in this area. The survey adopted a similar style of questioning to that used by Robinson, Loch and Croft (2015) in their study of student perceptions of screencast feedback. While appropriate ethical guidelines, such as those of BERA (2011) were followed in conducting the research, explicit ethical clearance for this study was not sought as: the nature of the questioning and collected information was not deemed to be sensitive in nature; responses were received on a non-compulsory, anonymous and an 'opt-in' basis; and, the purpose(s) of the study were made clear to participants at the outset.

A total of 74 responses were received to the survey, representing an approximately 9% response rate: 31 were from those who were, at the time, in year 1 of their studies; 29 were in year 2; 13 were in year 3; and, one in year 4. Given the limited response rate for year 4, where the discussion considers responses by year of study, the single year 4 respondent has been excluded.

4. Results

As Figure 2 shows, there was no clear consensus upon whether students felt they had received sufficient feedback on their work, with roughly comparable numbers answering 'yes' and 'no' (48% vs. 38%). There is little difference in the responses for years 1 and 2, however those who were in year 3 and responded were generally more positive about the level of feedback they had received although the sample size here is much smaller.

An analysis of the free-text comments provided by respondents reveals that seven (of the 35) who felt they had received sufficient feedback on their work linked this to the provision of 'model' or 'worked' solutions to the problem sheet exercises, particularly when they are provided in a prompt and easily accessible manner:

> *"Feedback was the most useful when it was returned promptly so you hadn't forgotten the material. General feedback from worksheets was very useful if it was intelligible enough. (typed rather than written)."* [S10, Yr3]

> *"Detailed solutions improve understanding so that I can ensure I make as few mistakes as possible. More problems and solutions should be available!"* [S30, Yr4]

But of those 28 who said they had received insufficient feedback, eight also highlighted the value of worked solutions which indicates the expectations of students in relation to feedback clearly extend beyond the provision of worked solutions alone:

> *"Model solutions were very helpful when it came to revision."* [S26, Yr2]

> "*Worked solutions on canvas enabled you to go through the solution step by step*." [S64, Yr1]

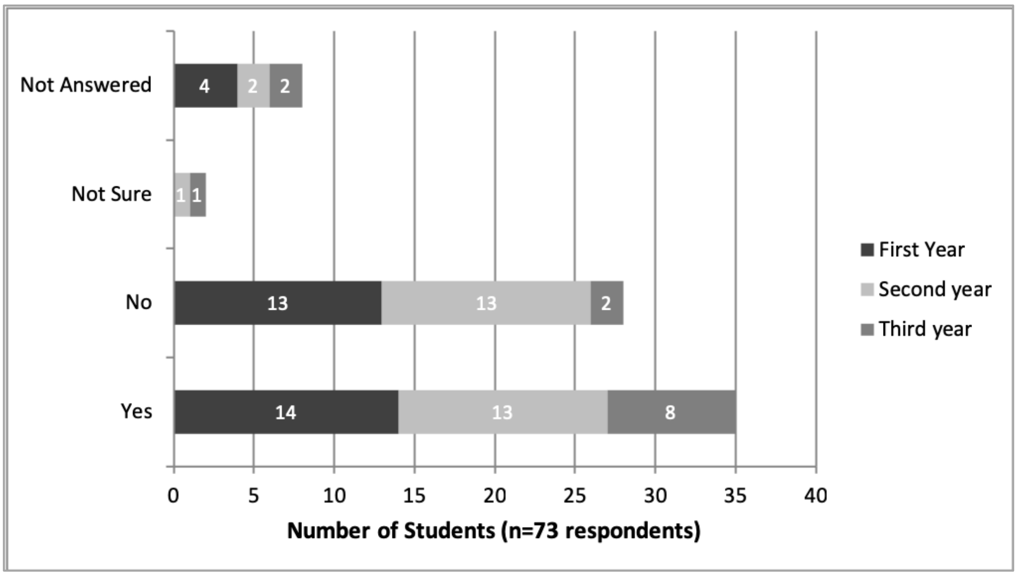

Figure 2: Overall, do you feel you have received enough feedback on your submitted work?

Complementing the availability of model solutions for each assignment is generic feedback, that is written comments on the performance of all students along with the highlighting of common errors or misconceptions. Only two students referenced the value they found in this form of feedback, but overall, student comments referred to its lack of a personalised nature:

> "Some just give general conclusions same for everyone which I can recognize myself." [S19, Yr2]

> "Some modules gave generic feedback on mistakes that students made overall but it wasn't tailored to my work." [S20, Yr3]

The provision of worked solutions should be a simple task for departments since they will already exist in order to support the marking of problem sheets, although there are sometimes valid reasons for these not always being made available. What is particularly interesting to note is how students commented that they used these solutions to reflect upon their own learning; a skill critical to the effectiveness of the provided feedback (Yorke, 2003). Such solutions are generic, they do not identify where an individual student has gone wrong and the students therefore need to do this for themselves, but it does appear that the availability of worked solutions does, at least amongst some students, provide the incentive to develop their necessary skills in self-analysis and reflection; here nine students provided specific details of how they used the worked solutions as part of their own learning process:

> *"Model solutions are helpful because I can see step-by-step solutions to compare with my own, and see which parts I haven't understood properly or need to explain more clearly."* [S7, Yr3]

> *"Read through exemplar solutions and tried to understand my mistakes."* [S49, Yr2]

> *"I compared it with my own solutions and learned to implement the methods the lecturer used."* [S66, Yr2]

Whilst there was less overall reference to 'model solutions' amongst year 1 respondents, in the instances where there were, their use again demonstrated evidence of the development of skills in self-analysis:

> *"I have submitted half of the work only as sufficient feedback wasn't available, so I used to mark my work when the solutions were made available."* [S40, Yr1]

> *"I compared my answers to model solutions and used them to draft future answers."* [S42, Yr1]

Some disciplinary surveys (for example Blair et al., 2012) have found that students express little concern about the amount of feedback they receive on their assignments, however others have highlighted not only the variations in student expectations that exist between disciplines but also mismatches in staff and student expectations (Brinkworth et al., 2008). Here, it is clearly a concern for any department when around 40% of respondents to such a survey highlight issues with the amount of feedback they receive during their studies

(Figure 2). This may not be surprising because as Tomlinson (2014; p6) notes within the UK "*the marked increase in fees is affecting students' views of what they expect from higher education… they also feel it is up to them to 'get as much out' of the experience as they can and maximise whatever opportunities HEIs provide*". This does raise a fundamental question as to what, from the perspective of a learner, constitutes the point of 'I have received sufficient feedback' being reached?

In general it appears, across all years, that where students felt they did not receive sufficient feedback, this was related to the marking of their problem sheets in particular, highlighting the lack of detail in the comments as an area where it would be worth departments focusing their attention:

> *"No, comments were generally not detailed enough."* [S2, Yr3]

> *"no - problem sheets are the main way to track progress and are not marked well enough."* [S24, Yr1]

> *"I feel like the problem sheets could have more feedback as it is often very generic and doesn't say where particularly I have gone wrong."* [S58, Yr1]

Such comments were further reinforced where students were asked to rate the quality of the different types of feedback they had received. Here 'comments written on your problem sheet' ranks lowest of all possible types (Figure 3) with 32 out of 74 respondents ranking this as either 'Below Average' or 'Poor'. Perhaps surprisingly, 'mark on your problem sheet' not only ranks relatively highly, this was cited as the fourth best form of feedback overall (Figure 4) with 30 out of 73 students raking this as either 'Above Average' or 'Excellent'.

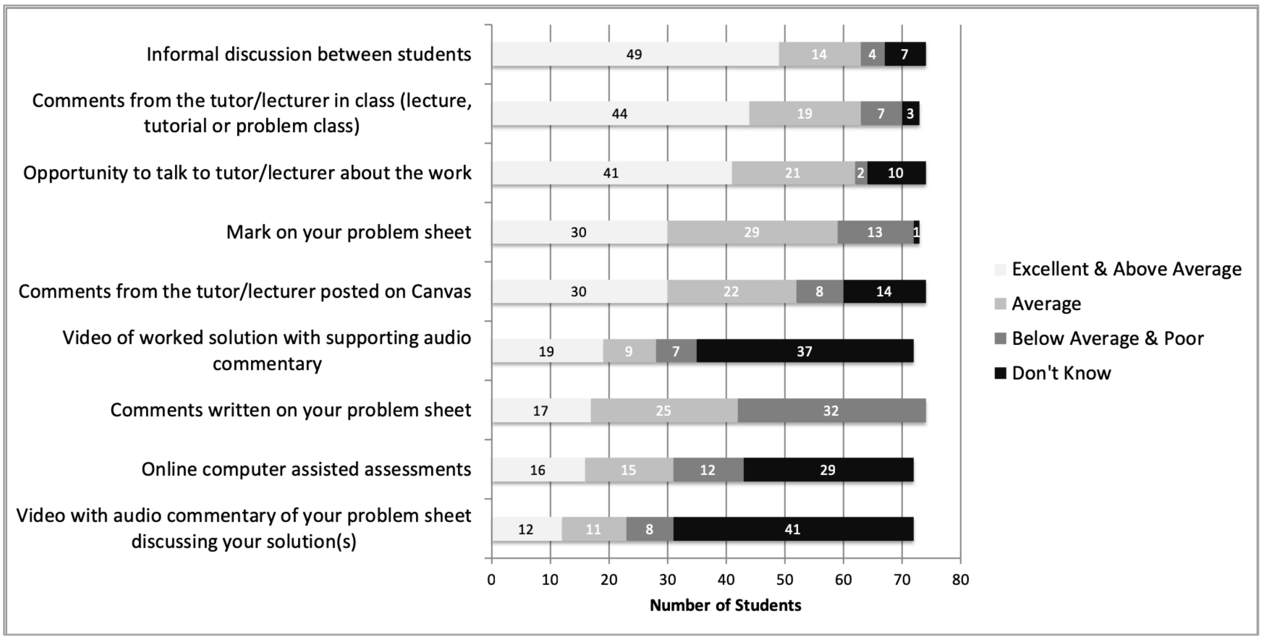

Figure 3: Of the feedback types you said were available, please rate the quality of the feedback you received.

Most interesting here is that two of the top three ranked forms of feedback cited as being most effective by students are based around dialogue – that is discussion of their work with either their peers or staff members. Overwhelmingly, dialogue with peers was the form of feedback students reported using the most during their studies (Figure 5) followed by the mark on their problem sheet. The link between the mark awarded and subsequent dialogue is not as surprising as it may seem as the mark can be used as the ‘prompt’ to stimulate individual learning and discussion with peers:

> *“My mark told me generally how well certain parts of the module had gone so that when it came to revision I knew which parts to focus on more.” [*S5, Yr3]

> *“Discussed what marks my friends got and compare our answers. Use my marks to see which questions I need to revise more.”* [S18, Yr2]

> *“I find discussion the best as often if you haven't done too well seeing a low mark on the page can be quite negative whereas by talking to a tutor they are able to pin point where you went wrong and how to gain marks.”* [S37, Yr1]

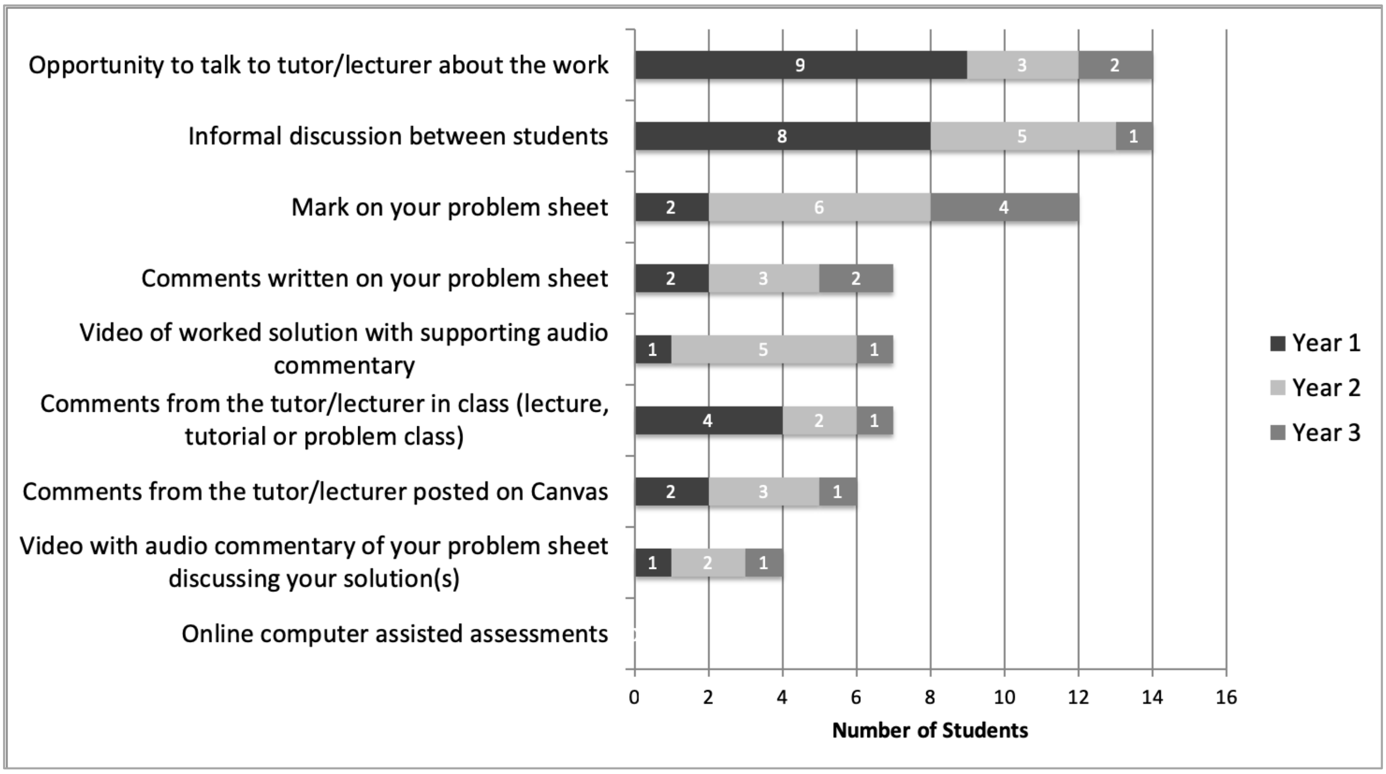

Figure 4: 'What was the best feedback you received?

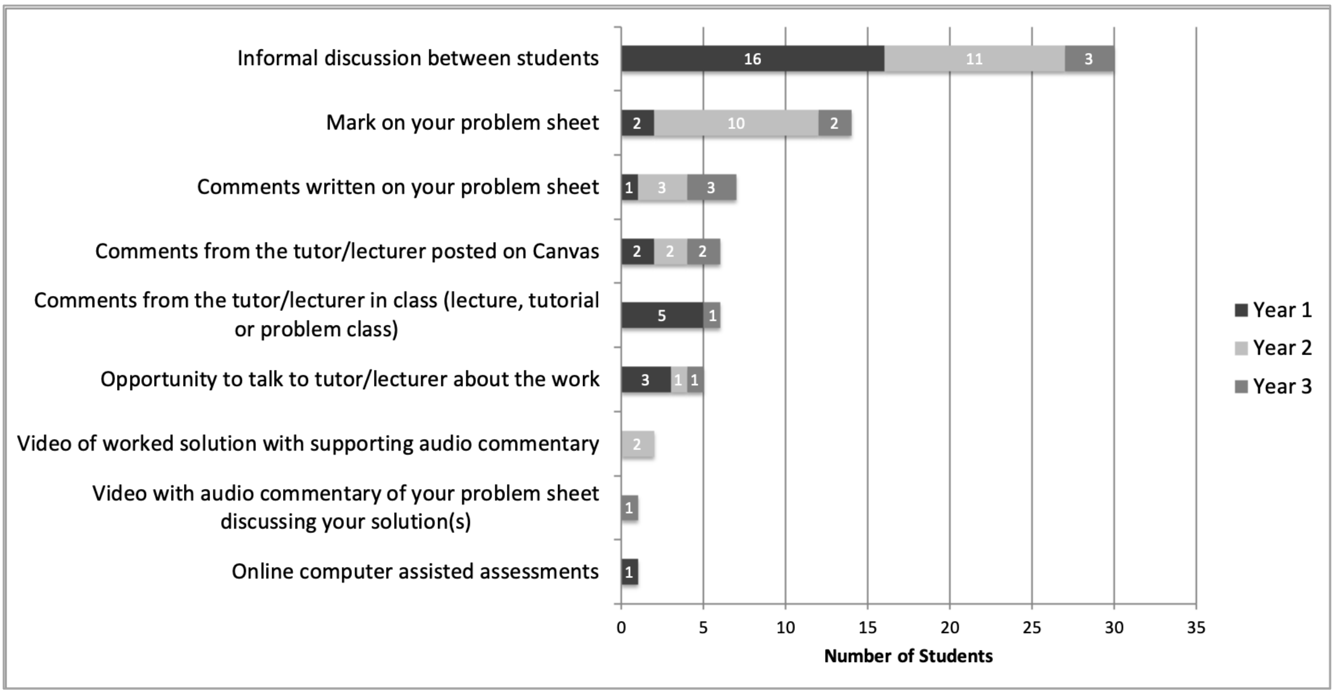

Figure 5: Which feedback have you used the most?

Although dialogue is highly valued, verbal feedback from a member of staff, for example at the start of a session also ranks highly amongst the best feedback received. Such comments might be used by students as a starting point for subsequent dialogue, and comparing results from Figures 3 and 4 shows that students cite the ability to talk to staff about their work as being amongst the best feedback they have received. However, only 5 survey respondents used this as their most common form of feedback which either suggests students choose not to engage with such opportunities, or there are insufficient opportunities accessible to them. It was year 1 students who, in the main (Figure 4), highlighted talking to staff as the most effective form of feedback; comments were directly related to the compulsory year 1 tutorial system highlighting its success as a means of increasing the effectiveness of feedback through genuine dialogue:

> *"Weekly tutorials with approachable tutors who have a clear understanding of the topics was also so useful, seeing how they and other students would attempt problems was very useful and motivated me to try harder…"* [S37, Yr1]

> *"Discussion in tutorials as allowed you to see how you can approach different questions on the same type and how to think of questions in a different way."* [S52, Yr1]

> *"Tutorial sessions were useful as I could get help on the areas I personally struggled."* [S58, Yr1]

And again, explicit links were made with the mark received on a problem sheet:

> *"Because if you don't understand something then talking to a lecturer about it really makes you get to the bottom of it. Then again, I often don't know that I don't understand something unless I lose a mark in a problem sheet for it."* [S47, Yr2]

The comments made by respondents about the feedback they received were often general in nature, but where individual modules were referenced these related to the new modules that were implemented as part of the curriculum review, Mathematical Modelling and Problem Solving (1MMPS) and Mathematics in Industry (2MI):

> *"2MI feedback was very helpful because it gave a very clear way to improve the work."* [S15, Yr2]

> *"Feedback on MMPS group projects was helpful in that it allowed me to improve upon and become more confident in my abilities to work with others in a group and problem solving skills."* [S42, Yr1]

> *"Feedback was good, detailed and helpful, especially in 2MI communication projects and research projects."* [S49, Yr2]

Whilst the emphasis in both of these modules was upon group-based tasks and extensive opportunities for dialogue with peers, staff members and PGTAs, they also piloted the use of technologies to enable students to access video (including audio) based feedback of their work; 13 students made explicit positive reference to its use in these group-based modules:

> *"2MI had voice and video feedback which went through the submitted work and pointed out strengths and weaknesses within the piece."* [S16, Yr2]

> *"Online feedback for MMPS was very detailed and helped us to improve the next projects."* [S48, Yr1]

> *"It was useful and informative as it was very detailed and applied to our specific work in MMPS."* [S36, Yr1]

> "*Impressive amount of personal feedback. Best way to give this sort of group feedback*." [S74, Yr2]

When questioned as to why this video-based form of feedback was preferred, comments related to the level of detail that it could provide, and in particular its ability to highlight and explain where the student could improve upon their work:

> *"I got very detailed analysis in my video so I understood a lot better where I had gone wrong and why."* [S14, Yr2]

> *"Yes I did watch it and my team and I used it to see what we have done well and what we can improve for next time."* [S29, Yr2]

> *"It was useful to go through everything we did and highlight issues along the way."* [S57, Yr2]

In addition to the use of video-based feedback in these new project modules, a two-week pilot of its use with weekly problem sheet marking (for year 1 students) was undertaken, along with a pilot in a year 3 module, to see if the benefits observed in 1MMPS and 2MI might be replicated more widely amongst the student cohort. Although this pilot was limited in its scope, there were positive comments on its use although these were much smaller in number. Positive comments indicated that it was more detailed than the feedback previously provided:

> *"Online feedback had a better feedback as it had more information given as to why marks were awarded or not."* [S1, Yr3]

> *"It was also used once on the problem sheets which was much better than normal marking."* [S39, Yr1]

> *"…it did help me clearly see the parts where I took the wrong direction with a problem or failed to realise what was being asked of me. I would take more time with*

my work after watching the videos as it was usually small errors that cost me marks." [S35, Yr3]

Overall, whilst there were clear positives relating to the use of video-based feedback for the different assignments, there were also negatives. These typically related to the length of the feedback which was most likely as a result of a deliberate attempt by the markers to provide more detailed feedback on submissions:

"Very long, helpful but very boring." [S22, Yr1]

"It often wasn't in depth enough and just pointed out what was done well and what was done not so well opposed to explaining why it was good or bad." [S37, Yr1]

"...I think less 'waffly' feedback would be good, just get straight to the point with what we need to do but this is more the person giving feedback rather than the feedback itself." [S70, Yr2]

"Harder to utilise as it was in a lengthy format." [S71, Yr1]

Student views upon the approach of using video-based feedback for the problem sheets were also mixed; the format of video-based feedback is welcomed, but they want it to be much more focused and easier for them to subsequently utilise:

"I prefer to have feedback on paper when it comes to problem sheets so that I can make corrections straight away." [S21, Yr1]

In addition, whilst seven students commented specifically upon the convenience of being able to submit their work online, six students were very negative towards the approach and instead indicated they would prefer to hand-in their solutions as had been the case previously:

"*Submitting electronically is a lot of hassle. Easier to physically hand in.*" [S17, Yr3]

"*Once the files were on the computer it was easy to upload them to canvas, but it seemed like a bit of a nuisance to either have to scan in a piece of work or take a clear photo*." [S27. Yr1]

Some of the negative issues noted above might be addressed as PGTA markers become more experienced at providing video-based feedback, and students more familiar with the submission process. As such it may seem that video-based feedback on individual problem sheets has the potential for the provision of more effective feedback upon student work. However it is important to understand its impact upon those who are providing the feedback and in particular the implications for the amount of time this takes. Within many mathematics departments, it is PGTAs who will often have a key role in the marking of problem sheets, particularly within year 1 and year 2. As this was the case here, a related short survey of 12 postgraduate teaching assistants who provided video-based feedback was undertaken to understand their views. From the responses received, it was clear that this is a much more time intensive process than traditional paper-based methods of marking and feedback (Figure 6):

"Time spent recording and uploading viable recordings probably took about twice as long as writing due to the need to pre-read through work and having to additionally upload and attach the recording." [PGTA6]

"Overall, even in the best case scenario - it took around twice the time to complete." [PGTA11]

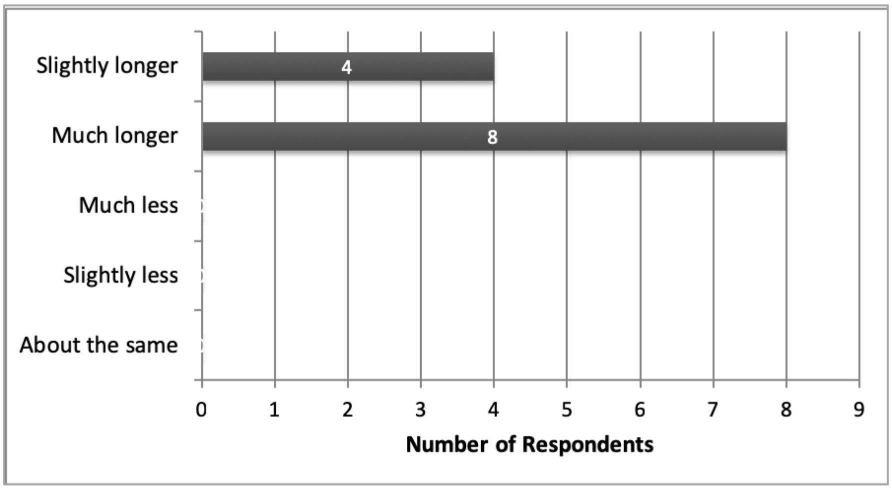

Figure 6: Compared to the time it would take you to grade the same submissions but in a paper format, how long did it take you to complete all duties associated with marking the student work?

Whilst postgraduates reported that it took longer to provide feedback in this form, only five PGTAs reported that they thought their comments were more detailed as a result. PGTAs also reported that the feedback was more difficult to provide, not only in terms of the administrative aspects associated with downloading and re-uploading submissions, but because they were planning their feedback in advance rather than simply providing it in real-time as was initially expected:

> *"It was the same but in this case the feedback was more difficult to give (as I had to think for a moment and plan exactly what I would say)."* [PGTA4]

> *"…being locked into giving feedback over an audio system can be somewhat stressful compared to writing down feedback where you can take a while to think of how to phrase a comment correctly."* [PGTA12]

More broadly, the PGTAs noted a range of practical issues associated with marking duties using this format that may be difficult to overcome:

"...you have to be fully concentrating on the marking and nothing else the entire time…you can't do it on the train etc…" [PGTA1]

"...can't give verbal comments in an office environment, needs to be careful to not accidentally post files to the wrong people." [PGTA3]

The differing responses here clearly identify a challenge for departments. It is the case that some, but by no means all, students value video-based feedback, but delivering feedback in this form is not at all well-liked by PGTAs (Figure 7). In particular as one PGTA commented:

"I find it hard to believe that the organisers of this experiment would have undertaken the work if they had to do the online grading themselves as it is so time-consuming. There is no way that the hours we were paid for covers the time wasted in the unnecessary administrative aspects of this task." [PGTA10]

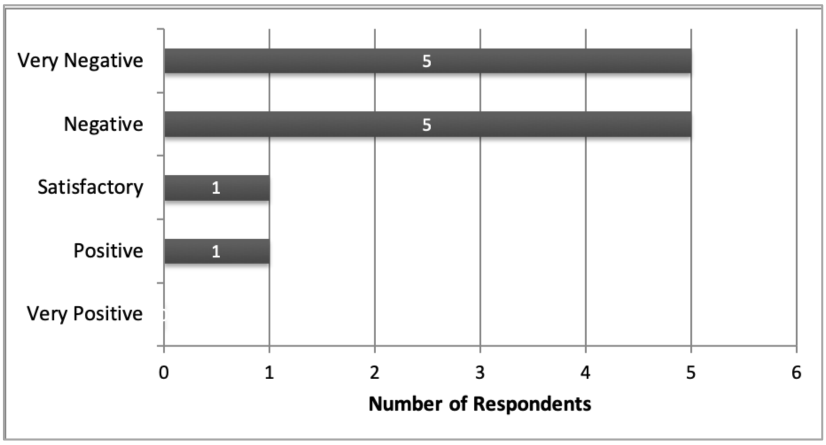

Figure 7: How would you rate your overall experience of electronic marking?

There are cost-benefit considerations for departments in terms of the amount of marker time needed to provide such feedback, and the willingness of PGTAs to undertake it, versus the benefits offered to learners. There does, however, appear to be a balance available in how video-based feedback may be effectively used as noted by one additional PGTA involved in the trial but who sent subsequent comments via email:

> *"I think the electronic marking is, in general, a good idea for certain modules (e.g. MMPS - I am not so sure if it would work for the 1st year example sheets). The type of submitted work has to be tailored to the fact that the feedback will be given electronically. For example, I think for a 10 page project it works, whereas for smaller questions broken up into parts it might not work so well."*

This aligns with the positive comments received by students on its use within group-based projects as we have noted earlier.

5. Discussion and conclusions

The findings presented here offer an insight into some of the feedback practices of a large research-intensive mathematics department. They also identify some key principles upon which others might build.

When viewed from the perspective of the student, it is clear that amongst those students who responded the feedback comments currently provided on problem sheets offer limited perceived value; this is despite the considerable effort that has been put into trying to enhance this aspect. What is seen as more important to the student is receiving a mark on their work, so that they can obtain some judgement on their overall level of performance, along with a clear and obvious indication of where mathematical mistakes have occurred. This is not to suggest that students are only interested in their mark. Whilst there has been discussion about the merits of 'gradeless assessments' (see for example McMorran, Ragupathi & Luo, 2017), as noted by Carless (2006), although students indicate they may first look at the mark awarded, they also want to improve and are genuinely interested in tutors' responses to their work. Our findings reinforce this latter aspect with the perceived value students place on dialogue with staff members about their work. Although it may seem counterintuitive, it may therefore be more effective for mathematics departments to remove written comments altogether. Doing so would also have the positive consequence of being able to speed up the return of student work, a fact which is known to be vital for the overall effectiveness of feedback (Gibbs & Simpson, 2005).

If written feedback comments on student problem sheets are removed, what feedback mechanism(s) might replace them? General comments on an assessment task made by an academic staff member, for example at the start of a formal session, are noted as being valuable by students and these might then be used as a basis for stimulating subsequent dialogue with the student(s) if the staff member actively encourages questions and comments. Complementing this approach, written generic feedback could also be provided via the VLE that summarises the overall cohort performance on the assignment; this also forms a more efficient means for the marker of highlighting where, for example, common mistakes and misconceptions have occurred. Most significantly, however, model or worked solutions are widely regarded by students as being a vital source of feedback. Their natural existence to support the marking of problem sheets means that they can be made available to the student cohort within minutes of a submission deadline although they could readily be extended to incorporate the generic feedback on cohort performance noted above. There are, however, often quite valid reasons for not immediately uploading worked solutions, for example some students having been granted an extended deadline, but at the very least, worked solutions on formative problem sheets should be readily available when students receive their returned work.

These approaches to the provision of feedback are generic, that is they are aimed at the cohort rather than an individual, and as such transfer the emphasis on identifying the exact nature of a mathematical mistake, and its correction, from the marker to the student. For this approach to be effective, it is essential that students develop their skills in self-analysis and reflection in order to be able to interpret such generalised feedback in the context of their own self-improvement and departments clearly need to support this. This is not only an important mathematical skill, see for example the seminal work of Polya (1945) whose fourth principle of problem solving is 'looking back', but one which will also benefit their wider employability skills (Marais & Perkins, 2012). A means of achieving this is through the provision of regular sessions on how to consider and use feedback to aid learning throughout the undergraduate programme, a variant of the "*Assessment Dialogues*" proposed by Carless (2006; p220) and discussed earlier. The available evidence indicates that our embedding of such activities within the tutorial programme, through both development sessions (Collis & Sivantharajah, 2014b) and examples in practice, does appear to have been effective although there exists scope for its extension and reinforcement throughout subsequent academic years.

Whilst there is clear benefit to a department, at least in an efficiency sense, by having an emphasis upon generic feedback, it does very much remain the case that students greatly value personalised and individual opportunities for feedback. Such feedback does not necessarily have to be provided by academic staff, indeed students cite their friendship groups as being one of the best sources of feedback, and so departments can think about the provision of learning spaces where such interaction can be naturally facilitated. For example, Croft, Grove and Bright (2008, p15) report on the pilot of a dedicated learning space for year 2 students within a mathematics department which was very effective at informally stimulating dialogue and peer learning: "*many students attend the centre in groups to work informally on coursework problems; peer support within these groups is often clearly* *evident…there were also a number of discussions held amongst students regarding aspects of their courses other than assessed work…*". Going further, Waldock (2015) reports on the impact of a custom-designed departmental learning space for mathematics where "*student comments indicate…increased motivation to use the space to engage with curricular and extra-curricular activity, to take part in group work and to form an active learning community*."

Whilst departments can facilitate such opportunities for peer learning and dialogue, both formally (for example establishing PASS schemes), or informally (through the provision of student learning spaces within departments), it is possible students will either not recognise this as being feedback, or will identify it as feedback that is de-coupled from the departmental provision. Both are a risk to the scores of a department within the context of the NSS although departments could legitimately highlight to students the role of these activities and spaces in contributing to the feedback they receive upon their learning. It is overwhelmingly the case that students value opportunities to discuss their work, either with their peers, PGTAs or staff members. As such, time spent providing written comments might be better used in providing further opportunities for dialogue, such as an informal drop-in environment, that is not the office of a staff member, where students can attend to meet and discuss their work with either the marker or an academic member of staff. Such a finding has been reported in other studies and as such is applicable to disciplines outside of mathematics. For example, in their systematic review of the engagement of learners with feedback Winstone et al. (2017, p24) identified that "*many papers emphasized a need to promote opportunities for face-to-face dialogue and peer-feedback activities*." A further, although more challenging suggestion, involves restructuring modules such that there are significant opportunities for students to work in teams on problems and tasks as we have found to be the case with the new modules 1MMPS and 2MI.

Although we have not discussed this in any detail here, there is increasing evidence that specialist mathematics students, many of whom are actually doing rather well, are also choosing to utilise mathematics support centres as a means of engaging in personalised dialogue with an independent tutor about their learning (Grove et al., 2019b). This reinforces the value of the drop-in model for feedback identified above. Although not universally common, such student usage is perhaps not surprising as coupled with the increased availability of mathematics support, numerous studies have highlighted the value to students of the personalised and one-to-one support available in drop-in centres that is not available in a tutorial or lecture environment (Lawson, Croft & Halpin, 2003). Indeed the value of this personalised learning and support is found across a range of disciplines as studies have indicated that students are particularly receptive to advice received during one-to-one feedback dialogue sessions (Duncan, 2007) and view these as 'safe spaces' within which to engage in dialogue about their work (Cramp, 2011). Our next stage in the action research approach we have described involves the design and piloting of mechanisms across other modules that allow students these increased opportunities to discuss their own work with staff and PGTAs as part of their learning experience.

Whilst there will exist a role for technology in enhancing the provision of feedback in the mathematical sciences, how it is implemented requires careful consideration with the views of both students and those undertaking the marking and feedback needing to be sought. Our findings echo those of others who have implemented video-based feedback in that it is liked by a number of students (Robinson et al., 2015), although we have found this to be in no way universal. Although the reported negative issues might be from students averse to a change in the feedback process, there are more substantial negative views to providing video-based feedback by the PGTAs who have a key role in the marking of formative work in the mathematical sciences within many institutions. Particular concerns are noted with the amount of time providing feedback in this form takes. Some studies have indicated that providing video or screencast feedback is more time-consuming (Haxton & McGarvey, 2011), however others have identified that it is more time efficient (Edwards, Dujardin & Williams, 2012), although in both cases these were disciplines outside of mathematics and involved staff members rather than PGTAs. It is likely that the speed at which an individual can provide video-based feedback will increase as they develop fluency with the technical aspects of the system, however the PGTAs surveyed here indicated that providing the actual feedback itself was far more time-consuming through a video-based medium. Addressing this will be a challenge as there is a constraint upon just how many hours of teaching and marking support a PGTA can reasonably provide and as such thought must be given to the assessment and feedback process as a whole. Where video-based feedback does however offer benefits is perhaps in extended pieces of student work, such as either individual or group projects, which are less frequent and numerous in nature, or in providing (generic) feedback on the performance of an entire cohort in an assignment (Crook et al., 2012).

There exists a very natural desire by departments to provide 'more helpful' feedback to learners, but doing so requires a delicate balancing act between the tasks of providing sufficiently detailed and timely feedback, equipping students with the necessary skills in reflection and self-awareness to be able to use this feedback effectively for themselves, and balancing the workloads of those undertaking marking and providing feedback. Within many mathematical sciences departments a small number of PGTAs will be tasked with providing feedback on the problem sheets of a large number of undergraduates, and as such, from the departmental perspective this involves managing the balance between providing learners with sufficiently detailed feedback for it to be usable, but managing the time and cost implications of having PGTAs fulfil this duty. This will no doubt also be a challenge for departments and disciplines outside of mathematics.

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