Feedback for enhanced student performance: Lessons from simple control theory

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Abstract: Repeatedly students express dissatisfaction with the feedback they receive and academic staff express similar levels of frustration, not least with students not reading, let alone applying, the feedback they have spent much time generating. The problems surrounding academic feedback are perhaps surprising considering the ubiquitous and necessary nature of feedback in our everyday lives, and our successful use of it without giving it much, if any, conscious thought. This paper investigates the comparison between the nature, value and use of feedback in simple control systems and that of the feedback offered to students in the academic world. It firstly considers how feedback is utilised to produce closed-loop control systems compared to open-loop systems and the advantages accrued thereby. It then discusses three aspects, timeliness, appropriateness and application, of the successful implementation of control system feedback and applies them to academic feedback, with a view to better understanding academic feedback and to improve its effectiveness in enhancing student performance. A case is made for student generated feedback and a trial is described which endeavoured to encourage students to do this. Whilst recognising the complex nature of the role of feedback within the total student experience, an attempt is made to look afresh at the requirements of successful academic feedback from a novel perspective.

Introduction

Many studies have been carried out to gain insight into the nature, use and value of feedback, both from the student’s perspective as well as from the academic’s viewpoint. These studies have considered a wide range of aspects of feedback, including delving deep into the detail of what are the best words to use, the use of novel delivery methods and the reactions of the recipients (e.g. Weaver, 2006) Much of this work has relied on data collection from both students and academics, with subsequent analysis and conclusions being drawn (e.g. Bailey 2009, Burke, 2009) In such studies, when commenting on its role in enhancing student learning, terms used to describe feedback have ranged from ‘Important’, through ‘Central’, ‘Key’ and ‘Essential’, to ‘Cornerstone’ (e.g. Roberts 2010).

The generating, giving, receiving and applying of feedback is undoubtedly a complex process, which has a plethora of parameters associated with it, many of which are difficult, if not impossible, to isolate and analyse. Consequently it appears to be very difficult to develop strategies for producing good effective practice in the use of feedback.

However it is perhaps surprising that the feedback process causes such difficulty and is so hard to ‘tie-down’, considering the ubiquitous nature of feedback in everyday life. The human body would not survive without effective feedback. Breathing, temperature regulation, movement and a countless number of other functions all depend on feedback. We all generate, process and apply feedback continually and apparently quite naturally, with giving it little or no conscious thought. As we are so ‘at home’ with the use of feedback in our every day life can we draw from its use any significant insights that could be applied to academic feedback, in an attempt to improve its effectiveness?

The purpose of academic feedback, whether by design or accidently, is complex and far from singular in nature. Feedback can be an encouragement to the recipient, it can help to instil confidence in any
marks given, and it can help to focus the mind of the assessor, as well as provide the necessary insight to facilitate improvement both for tutor and student. (Carless, 2006) We shall in this paper however limit our consideration to feedback in its role as enabling improvement in students' learning and performance, and consequently concentrate on those aspects of feedback which could be influential in this case. It is believed that this should be the main purpose of feedback, a view supported by the Quality Assurance Agency’s Code of practice (2006), which places the “promoting of student learning by providing the student with feedback, normally to help improve his/her performance” at the top of their inclusion list of the purposes of assessment, and states that “Institutes provide appropriate and timely feedback to students on assessed work in a way that promotes learning and facilitates improvement”.

This paper will consider 3 aspects of feedback as utilised in simple control systems, namely timeliness, appropriateness and application, and then seek to apply lessons gained to the implementation of feedback in the educational context, especially within the Higher Education (HE) sector.

Control systems that employ feedback in one form or another are referred to as 'closed-loop' control systems, whereas those that do not utilise feedback are known as 'open-loop' control systems. Firstly we will briefly review the nature of these two control system configurations.

### Open-loop control system

![Open-loop control system](image)

In an open-loop system, as illustrated in Figure 1, the input controls the process so that the desired output is achieved. This produces a simple and often low cost control solution. For this system to work successfully the user needs to have an accurate and precise understanding of the behaviour of the process, as well as both the process and its environment remaining largely unchanged.

### Closed-loop control system

![Closed-loop control system](image)

In a closed-loop system, as illustrated in Figure 2, the input is termed the target and the process is controlled by the difference, referred to as the error, between the input target and the actual output generated. This error is produced by feeding back the value of the actual output and comparing it with the target. If the actual output is the same as the target then the required control has been achieved, and the error will be zero causing the process to no longer change the output. If there is a large difference between the target and the actual output then the error will be large and the process will change the output significantly in an attempt to reduce the error to zero. The origin of the term ‘feedback’ is clear, as it describes the backward direction of the feedback path as opposed to the forward control flow through the system.
These two strategies for achieving control are more thoroughly discussed in the chapter entitled ‘Control and Feedback’ (Storey, 2009), in which they are summarised as:

“Open-loop systems rely on knowledge of the relationship between the input and the output. This relationship may be ascertained by a process of calibration. Closed-loop systems operate by measuring the actual value of the output of the system and using this information to drive it to the required value.”

Application of open-loop and closed-loop systems

To illustrate the difference between these two strategies consider driving a car around a corner. Open-loop control would be when the manoeuvre was attempted with the driver blindfolded, relying solely on timing and past experience of how the car behaved when driven. You could press the accelerator to a given setting and after so many seconds turn the steering wheel through a predetermined angle before straightening it up again and applying the brakes. Assuming you knew exactly how the car behaved and the driving conditions remained unchanged, a corner could be successfully negotiated in this way. However even a small variation in the cars’ performance, or change in the road conditions, let alone a stray dog wandering onto the road could result in a far from satisfactory outcome.

By simply closing the control loop using feedback provided by the drivers’ vision, most if not all of these possible causes of failure can be overcome.

It should be noted that the feedback, being a passive parameter describing the proximity of the output, does not get the system to the ‘target’ output, nor does it energise or directly control the process, but is nonetheless vital to the system. The effective control of any system, other than the simplest and most stable, relies completely on feedback, and without feedback the system will almost invariably fail.

Continuous or discrete feedback

In the driving example used above the nature of the feedback is continuous. Throughout the manoeuvre the driver continually monitors the car’s position on the road and adjusts the controls accordingly. In contrast the discrete form of feedback only allows for adjustment to be made after the output is achieved, for example throwing a ball at a target. Once the ball is thrown no further adjustment can be made. Once the output is achieved the proximity of where the ball lands compared to the target can be obtained and fed back to the thrower, who can then make adjustments for the next throw.

Although these types of feedback appear different, the continuous form can be approximated by a series of the discrete form. The shorter the period of the series of discrete feedback the closer it will approximate to continuous feedback.

Feedback in the Educational Context

It is not known whether the term ‘feedback’ as used in education was adopted because of the use of the term in the context of control systems but it has surprised the author how few references are made to the apparent parallel within the abundant literature on assessment and feedback. However, two such references are by the Quality Assurance Agency (2006) where they give the example of “designing a feedback loop’ into assessment tasks” and by Nicol and Macfarlane-Dick (2004) where one of the seven principles of good feedback practice is stated as “providing opportunities to close the gap between current and desired performance”. These parallel precisely the purpose of feedback within a closed-loop system.

In drawing a parallel between the use of feedback in a closed-loop control system and the world of education the various components of the system require definition. In considering Fig 1 above the ‘Output’ can be defined as the student’s learning as demonstrated by performance, the ‘Process’ as the assessment task within the learning and teaching strategy and the ‘Input’ as the student’s engagement with the task. Let us now consider the three aspects of feedback as stated above.

Timeliness of feedback

Timeliness of feedback might be considered to be one of the most crucial aspects which influence the effectiveness of feedback. It has been suggested that if not offered immediately then a delay of 1 or 2
days is optimum (Race 2001), but due to practical considerations many institutions, Bournemouth University included, adopt a longer, 3 week turnaround time as being acceptable. One would think that the sooner the student can receive feedback the more likely it will be effective, as the assessed work remains relatively fresh in the student's mind and experience. However the question concerning timeliness is not just how quickly can feedback be generated but to what is the timeliness of feedback related?

By inspection of the diagram for the closed loop system above, it is clear that although feedback is generated at the output of the system, it is applied at the input to the process. This is essential for feedback to perform its function. By attempting to apply feedback at the output of the process no corrective action can be achieved. The figure below illustrates a typical implementation of academic feedback and illustrates how far removed it is from the implementation of feedback in a closed-loop control system.

![Diagram of closed loop system](image)

**Figure 3: Typical implementation of academic feedback**

Feedback must be applied at the input, therefore as far as achieving control is concerned the timeliness of feedback after the output is produced is an irrelevance. The relevance of timeliness is when it is related to the input. Feedback needs to be available when the input is applied to the process.

This consideration highlights a more fundamental aspect of feedback. Taking the example of driving a car around a corner the feedback is continuous, with the driver 'instantly', as far as a human reaction time allows, making corrections and so improving their performance. This is not however the model on which most assessment is based in HE. A typical unit or module of learning would be assessed by two assignments of varying nature. The work would be submitted, marked and returned with feedback, hopefully before the next assignment is set. Therefore any value in the feedback generated can only be applied to the input of the next assignment, and the feedback for the second, or last assignment if more than 2 are set, is of little or no value as far as improving performance is concerned. To apply this to the example of driving a car around a corner it would mean that the driver would be allowed to open their eyes once, half way around the corner, to take any necessary corrective action and then at the end to see how well they have done - clearly an improvement on remaining blindfolded for the whole exercise but surely not sufficient to ensure a satisfactory outcome.

As it may be impossible to offer feedback on a continual basis whilst the student is completing a given task, an approximation to it would be to split the assessment into a series of smaller tasks thus allowing for the feedback given for a particular task to impact on the student's input to the next task, as shown in Figure 4 below. This aptly illustrates that the true nature of ‘feedback’ is better described as ‘feed-forward’, if its intention is to improve learning and performance.

![Diagram of approximation to continuous feedback](image)

**Figure 4: Approximation to continuous feedback**
There are clear implications of adopting this model but the benefit gained by the student may well justify them. The use of draft report submission and marking allows for a measure of corrective action to be taken to improve performance, and no doubt this is of benefit. Students have commented that feedback on draft submissions is of more use than that on final versions (Carless, 2006). However, for close control of the process the more iterations the better. In pre-HE education this model is seen as the teacher observes and offers feedback to the students as they complete a given task in the classroom. This is also possible in smaller laboratory or tutorial sessions where the students’ work can be observed and feedback offered immediately. However, it has been observed that often HE students are reluctant to seek assistance or acknowledge their need of help when undertaking in-class or laboratory tasks, and as a result feedback has had to be ‘imposed’ on the students, by proactively observing and commenting on their progress as they work. If this is done sensitively then it has been found that most, if not all students respond positively.

The rush to get feedback to students in a timely fashion may well satisfy their natural desire to see how well they have done, but does little or nothing to help control the improvement in learning and performance. Feedback given at the output could be retained by the student and then applied at the input to the next task and it could be argued that a period of reflection upon the feedback would be a good thing before its application. In an ideal world this may work but with the pressures of studying a number of units simultaneously as well as the usual distractions that life imposes it is perhaps unlikely to be as effective as it might be.

**Appropriateness of feedback**

As illustrated above in the closed-loop control system for feedback to be effective it must be applied at the input of the process and therefore, as well as accurately reflecting the output, it must relate to the input. From the example of driving a car around a corner it can be readily understood that feedback on the temperature of the engine may well be 100% accurate and instantly available to the driver, but would be of little use in regulating the driver’s input in the attempt to perform the required manoeuvre. The designer of any control system must consider carefully the requirements of the input to the system when defining the nature of the generated feedback.

If academic feedback is to be utilised to improve students’ performance then although it clearly has to reflect the output of the completed task, it must be relevant to the next task to be of any real use. How often are the requirements for the next task considered when designing assignments, assessing student’s submissions or producing feedback?

A common approach to assessment is to divide up the Intended Learning Outcomes (ILOs) for any unit or module of study between the various elements of assessment, and to avoid assessing the same ILO more than once. This makes for a convenient and easily traceable mapping of student learning to the aims of the unit, but, due to the nature of ILOs tending to be distinct and unique, it does not lend itself to the production of feedback that is relevant to the next task and therefore effective in improving performance. Instead of assessing one or more ILOs in their entirety within one task it may better serve to assess parts of some or all ILOs in each assignment thus allowing each subsequent task to build on the previous one, and thereby making the production of input-related and hence performance-enhancing feedback more viable.

Based on the preceding considerations it is suggested that it is not the quantity of feedback that is important or even necessarily its accuracy and precision in absolute terms, but the appropriateness of the feedback in relation to the next input opportunity that will produce the required level of control.

If the model of a number of smaller assessment tasks was adopted as shown above then the desirable characteristics of timeliness and appropriateness, both as applied to the input, could be achieved.

This issue is further complicated by the adoption of relatively short units or modules of study, as Gibbs (2004) discusses in his section on ‘Modularisation’ and assessment. He comments that

“it is harder to plan sequences of linked assignments where each feeds into the next, when timescales are short and resources allow only one or two assignments in a module. It may be difficult to make any kind of arrangement that would make feedback flow forwards effectively”

It appears therefore that a more radical approach is necessary in the design of not only individual assignment tasks but whole units or modules and even complete programmes of study, to ensure that the contribution of feedback towards enhancing performance is optimised.
Application of feedback

It hardly needs stating that however timely and appropriate feedback is, if it is not applied or is applied incorrectly any potential benefit in achieving control will be lost. If the driver of the car attempting to manoeuvre around a corner chooses to ignore the visual feedback or is unable to effectively use it, they will be no better off than a driver without feedback; they may, in fact, be worse off. The driver with no feedback will have to rely on what they know of the car’s performance and the environment, whereas the driver who is unable to utilise the available feedback may have little or no other information on which to base any attempt to control the process.

For feedback to be effective in the control of a process it must be applied and applied correctly. In a simple control system there are two ways in which feedback can be used, one termed negative feedback and the other positive feedback. The former determines the difference between the feedback and the input, effectively determining how far the actual output is away from the target output, and produces a stable output which tends towards the target, as described in the section on a closed-loop system above. The latter adds the feedback to the input resulting in instability and tending to the extreme output of the process.

In a control system the physical difference between negative and positive feedback is often very little - in the field of Electronic Engineering it can be as simple as swapping over two input pins on an operational amplifier, resulting in circuit failure as complete as if the feedback were not implemented at all. This is a simple, easy to make mistake, even for more experienced designers.

Studies have shown there are a variety of reasons why students fail to apply feedback effectively or even at all. These include students being unable to read handwritten feedback, terminology that is not understood, feedback that is perceived to be irrelevant and students’ reluctance to read feedback that might lower their self-esteem (Weaver, 2006). Additionally it might be suggested that the delay, which in some cases can be measured in months, between receiving feedback and the next opportunity to use it is instrumental in students failing to effectively apply it.

Timeliness and appropriateness of feedback is the responsibility of the person who generates the feedback, usually the tutor, but the driving force behind successful application must come from the student. Students must be enabled and empowered to apply the feedback provided and apply it in a way that will enhance their performance. This means feedback must be understandable to the student, relevant and timely to the input of the next task.

Student Generated Feedback

There is no doubt that there are many ways in which attempts can be made to achieve the goal of effective feedback as illustrated in a closed-loop control system. However these will only be approximations to the analogy, for example the use of a series of small assignments or the submission of draft reports. Ultimately, the only way in which such feedback can be fully effective is for students to generate and apply their own feedback. To encourage and train students to generate feedback for themselves should be part of the purpose of tutor feedback and forms an essential element in training for Life Long Learning. Carless et al (2010) sums this up when he says “In essence feedback is sustainable when it supports students in self-monitoring their own work independently of the tutor”.

Only when students generate their own feedback, not just at the end of a task but continually throughout the task will effective control be available to them. As Gibbs (2006) comments:

“Ultimately the fastest and most frequent feedback available is that provided by students to themselves from moment to moment as they study or write assignments. Investing effort in developing such self-supervision may be much the most cost-effective use of tutors’ time.”

Use of ‘Self-Assessment of Performance’ Questionnaires

To apply the above considerations of timeliness, appropriateness and application and in an attempt to engender self-generated feedback, a trial was run during a first year unit on the Electronic Engineering programme at Bournemouth University in 2008. Having completed a summative assignment task the students were required to complete a ‘Self-Assessment of Performance’ Questionnaire which asked a series of Yes/No questions, such as ‘Did I complete the assignment?’ and ‘Have I properly referenced it?’, followed by questions demanding a descriptive answer, such as ‘One way I could improve the presentation of this submission’. The questionnaire concluded by asking the students to state two
things they would do to improve their next assignment. To encourage the students to use the questionnaire a small percentage of the overall mark rested on its completion.

The questionnaires were submitted a week after the hand-in of the assignment and they were kept by the tutor until the next assignment task was set, when they were handed back to the students with the next assignment brief. As part of the next assignment hand-in the students were required to conclude the submission with a reflective discussion on how well, or otherwise, the intended improvements had been realised.

This process was relatively easy to add to an existing assessment regime because it was aimed primarily at the more general aspects of performance rather than subject specific content. A more careful redesign of the assessment regime may be required if a more detailed questionnaire were to be deployed.

No rigorous evaluation of this trial was undertaken but it was noted that the students engaged well with the process and that it was perceived to be a worthwhile exercise.

Following on from this trial a modified version was adopted for a series of five laboratory exercises in 2010 and again in 2011. The unit was on year one of the Creative Technology Framework at Bournemouth University and was entitled Creative Technology Fundamentals. The laboratory sessions involved the design, build and testing of a series of basic electronics circuits which formed the building blocks for a simple single note synthesiser. As with the 2008 trial no detailed evaluation of the success or otherwise of the process was undertaken but it was noted again that the students engaged well and that for both years in their unit feedback questionnaires the students have rated the laboratory sessions very highly.

It is proposed to further develop the process for the next academic cycle and to carry out a detailed evaluation of its effectiveness.

**Conclusion**

Much of what has been considered in this paper is not new and has been written about by many other authors, not least in their ‘10 conditions under which assessment can support learning’ (Gibbs and Simpson 2004). However, by placing the role of feedback in closed loop control systems alongside academic feedback it is hoped that some of the aspects of the nature of academic feedback which are necessary to the enhancement of student performance will be brought into sharper focus.

It is clear from the consideration of a closed loop control system that the purpose and role of feedback is absolutely central and essential if effective control is to be achieved. The system simply would not work without feedback. Similarly to achieve the goal of enhanced learning and performance the production and application of academic feedback is not an ‘optional extra’ but is vital to the process. Additionally for feedback to be effective it must be available at the appropriate time, be suitable for the purpose and effectively applied. The common feature of these three imperatives is that feedback must relate to the input of the process, as well as accurately reflecting the output. This must be taken into account when designing assessment schemes within units of study and when producing individual assignment tasks. It may be necessary to take a radical look at the way HE is delivered, so that every aspect, including the structure of programmes is conducive to the generation and use of effective feedback.

The usual model of a small number of often loosely related assignment tasks within a given unit or module of study does not lend itself to feedback being used effectively to enhance performance. Some alternative models are employed which approximate to the way feedback is used in a closed-loop system, but all by their nature fall short of the optimal utilisation of feedback. The only way in which academic feedback can work as feedback does in a control system, is for the student to generate and apply their own feedback. Surely one of the most important aspects of education in general and of HE in particular is to encourage, educate and empower students to generate and apply their own feedback. Of course, even with effective control the output is only ever likely to be as good as the target that is set!
References


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