Feedback in the Classroom: A View from the Control Theory

Diego F. Sendoya-Losada, MSc[1], Gilma P. Andrade-Trujillo, MSc[2], and Shyrley R. Vargas-Paredes, MSc[2]
[1]Universidad Surcolombiana, Colombia, diego.sendoya@usco.edu.co
[2]Universidad Nacional Abierta y a Distancia, Colombia, gilma.andrade@unad.edu.co, shyrley.vargas@unad.edu.co

Abstract*– Students often express dissatisfaction with the feedback they receive, and teachers express similar levels of frustration, because students do not read or apply, the feedback they have generated. This paper uses some knowledge of control engineering, in particular, the subject of feedback control loops to give a different perspective about this by comparing the use of feedback in simple control systems and feedback offered to students in academia. Initially, the way in which the level of understanding or learning evolves in the face of different types of student participation is analyzed. Then, the impact of the different levels of support or quality of the comments provided by the teacher in the training work is analyzed. Finally, it is concluded that the quality of the teacher's comments, which is what has classically been interpreted as feedback, has a significant impact on student learning. However, it is the students' action that generates the feedback, and determines the quality and quantity of it.

Keywords—Education, Engineering, Feedback, Learning Outcomes, Professor Comments, Student Attitude, Student Work.

I. Introduction

Students frequently express dissatisfaction with the feedback they receive, and teachers express similar levels of frustration because students do not read or apply the feedback that they have spent so much time generating. Different studies have been carried out on the nature, use, and value of feedback, both from the student's perspective and from the teacher's perspective. These studies have considered a wide range of aspects of feedback, including the best words to use, the use of novel delivery methods, and the reactions of students. Many of these works have been based on the collection of data from both students and teachers; and different analyzes and conclusions have been extracted. In such studies, the terms used to describe feedback regarding its role in enhancing student learning have ranged from "important," through "central," "key," and "essential," to "cornerstone" [1] - [3].

The generation, delivery, reception, and application of feedback is undoubtedly a complex process that has a large number of associated parameters, many of which are difficult to isolate and analyze. Consequently, it is difficult to develop strategies to produce effective practices in the use of feedback. However, considering that feedback is present in many places and situations in everyday life, it is perhaps surprising that this process causes so much difficulty and is so difficult to implement. The human body would not survive without effective feedback. Respiration, temperature regulation, movement, and a host of other functions depend on it. All human beings generate, process, and apply feedback continuously and naturally, without consciously thinking about it [4]. Therefore, is it possible to extract any meaningful information from this that can be applied to academic feedback to improve its effectiveness?

The purpose of academic feedback, whether by design or by accident, is complex; and it is far from unique by nature. Feedback can be an encouragement to the student, it can help inspire confidence in the grades given, and it can help focus the evaluator's mind. In addition, it can provide the information necessary to facilitate improvement for both the teacher and the student [5]. In this article, consideration of feedback is limited to its role in enabling improvement in student learning and performance.

Feedback is often perceived by students and graduates as a major weakness in their student experience. This perception is likely supported by a lack of recognition and engagement with the feedback available. Although, it cannot be hidden, that sometimes some teachers do not do a good job of providing effective feedback.

Although the teacher does everything possible to help students understand the learning processes, instead of focusing on what students perceive as bad feedback; the real weakness is student recognition and inappropriate use of feedback rather than poor quality [6]. Of course, sometimes the teacher provides poor quality feedback.

Recent works have emphasized the need for students to be the main drivers of their own learning and for feedback to be a guide for the respective improvements. For example, that the best feedback will surely be useless if students do not use, assimilate, and implement it in their future works, is established by [7]. Students need to be supported to critique their own work, that is, generate their own feedback. Of course, it is implicit that the teacher provides mechanisms such as online questionnaires to help students do this. Reference [8] offers a different view in which the key point is that teacher feedback cannot or will not be used effectively by students unless they have an obvious opportunity and motivation, perhaps immediate, to use it in future works.

In this way, allowing the students to become active to generate their own feedback may be the best strategy for the teacher and the learning process. A particularly relevant work in the literature has focused on the so-called self-regulated learning, through which students are encouraged to be much more aware of their role in the learning process and of the importance of actively reflecting on their own interests, progress, feedback available, and their own needs [9].

Digital Object Identifier: http://dx.doi.org/10.18687/LACCEI2021.1.1.282
ISBN: 978-958-52071-8-9 **ISSN**: 2414-6390
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Similarly, another popular tool for encouraging students to become active participants in feedback processes is peer review. The goal here is to get students to reflect deeply on the evaluation criteria and the extent to which different works meet those criteria, so that they provide comments and justification for their grading. There are some advantages to having students receive detailed feedback on that work from their peers. Students are emotionally and mentally prepared to think carefully about the quality and weaknesses of their own work given the effort put into grading a peer presentation. This should also help them to be more specific when seeking clarification from the teacher [10].

A key focus of this document is the message that feedback comes in many forms and students should be vigilant and acknowledge feedback when it is available. Too often, students think that they are not getting feedback or that they are receiving poor feedback because they do not recognize the comments that are given as feedback. It is well understood in the general literature that feedback comes in many forms, some of which are teacher-generated, and some are self-generated (by the student), but students do not respond equally to or recognize each form of feedback, independently of its quality.

A popular method of improving student participation is regular assessment, for example, with short computer-based quizzes that provide instant feedback. However, it is interesting to note that when viewing multiple questionnaires online over the years, many students who have multiple of these questionnaires in a particular module often do not compare it to having received feedback on their work.

It is not known if the term "feedback", as used in education, was adopted due to the use of the term in the context of control systems, but it is surprising how few references are made to the apparent parallelism in the abundant literature on evaluation and feedback. When a parallel between the use of feedback in a closed-loop control system and the world of education is made, the various components of the system require definition. This document will use some knowledge of control engineering and, in particular, the subject of feedback control loops to give a different perspective to this subject, by comparing the use of feedback in simple control systems and feedback offered to students in academia. In this way, it is intended to demonstrate the importance of focusing on students' perceptions and understanding the feedback learning process and how the teacher can facilitate it.

II. Feedback In Control Systems And Academic Feedback

To make clear links to the feedback control diagrams, a simplified version of the learning process will be used. For this, Fig. 1 shows a typical block diagram of a closed-loop control system. Here the blocks represent processes/systems, and the lines represent signals. Typically, $G(s)$ is the process to be controlled, $H(s)$ is a meter or sensor, and $K(s)$ is the controller. Thus, for example, $G(s)$ can be a furnace or a boiler, in which some variable (y) can be controlled (e.g., temperature). For this, a sensor or meter is used and that measured temperature (y_m) is compared with the desired temperature (r). If there is any difference or error between them, then the controller $K(s)$ executes some action like sending more/less gas flow to increase/decrease the temperature in the boiler. Usually, the feedback loop is where $H(s)$ is.

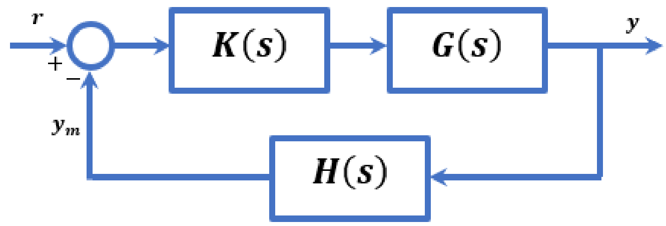

Fig. 1. Closed loop control system.

The learning process can be represented in a similar way, considering that it is a continuous and iterative process (Fig. 2). The use of this form of representation using block diagrams shows a clear analogy with feedback control systems. In this case, block $G(s)$ represents the work developed by the student, $K(s)$ represents the attitude of the student, and $H(s)$ represents the comments that the teacher makes about the student's work. The input (r) are the expected learning outcomes, and the output (y) are the achieved learning outcomes.

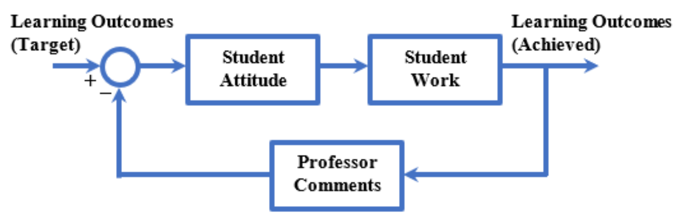

Fig. 2. Learning process.

In this way, to achieve the expected learning outcomes, students develop some type of $G(s)$ work (a task, a laboratory, an exam) and produce some result (y). The teacher generates comments on their work (for example, correct/incorrect or a more detailed analysis), and students should use this new information to react, reflect and make the necessary adjustments to improve their learning. This analogy can be used to better understand the learning process and, in particular, the role or importance of the different components $G(s)$, $K(s)$, and $H(s)$. It is implicit, in this analogy, that this learning cycle is iterative, which means that students should have opportunities to develop their work, receive feedback on it, and try again. In fact, this could be used as an argument to recommend the need for a much more formative assessment than a summative assessment.

Furthermore, without feedback (open loop) it is not possible for the student to achieve the expected learning. For example, if the student's work is represented in a simplified way using the transfer function: $G(s) = 0.6 / (s+1)$, where the time scale is given in weeks, then the learning achieved by the student can be observed in Fig. 3. An output equals to 1 represents a total understanding, in this case the learning only reaches 0.6; that is, only with the class entry and without teacher comment, learning is expected to converge to 60% of full requirements. Consequently, total learning requires more than just entering the classroom.

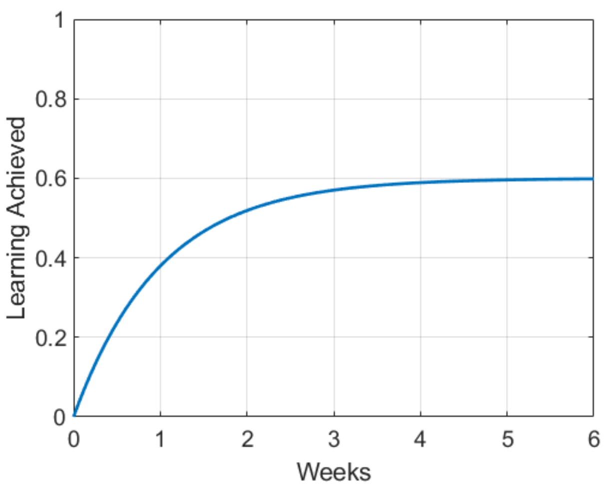

Fig. 3. Open loop response.

The following sections will focus on analogies between the different choices of the $K(s)$ and $H(s)$ components; and the quality of student reflection and teacher comments, in order to analyze:

1) What would be the impact of the reflection and participation of the students represented by block $K(s)$?

2) What would be the impact of the comments provided by the teacher represented by block $H(s)$?

A. Impact of K(s) on Learning

Now the student's work is entered in a system like the one in Fig. 2, where there is feedback. In this case, it is assumed that the teacher's activity is represented by $H(s) = 1$, which indicates immediate and complete comments on the students' work. Therefore, applying the rules of control theory to reduce block diagrams, the closed-loop learning process can be expressed as follows: $KG / (1+KG)$.

As the student is intended to achieve full understanding, then: $KG / (1+KG) = 1 / (s+1)$.

With feedback, the learning process has a time constant of one week and students will reach near complete understanding in approximately 3 weeks with perfect teacher support. To achieve this, the value of $K(s)$ should be: $K(s) = (s+1) / 0.6s$, or $K(s) = K_p + K_i/s$.

That is, a fully conscious student will be represented by a PI compensator:

- The proportional term (K_p) represents how instantaneous the student's reaction is to new information, but without reflection. If K_p is too large, students overreact to new information, and therefore their understanding is expected to be chaotic/oscillating. If K_p is too small, students underreact which represents disinterest and inattention.
- The integral component (K_i) represents the process of reflection and, therefore, although learning is slow to progress, it can converge towards full understanding. A larger integral term represents more active reflection and engagement, and a smaller integral means that the student is slow to do this or simply does not spend enough time.

Here the analogy is between a proportional response that is a quick response to comments and an integral term that is linked to continuous reflection and correction by the student. Without prompt commitment, student learning will be slow. Without proper reflection, student learning will not converge to correct understanding.

The following options represent different types of student participation. The way in which the level of understanding or learning evolves for each case is presented in Fig. 4:

- A choice of $K(s) = K_1 = (s+1) / (0.6s)$ is ideal with a good balance between immediate response and careful reflection (i.e., the proportional and integral components) for the learning to fully converge in about 3 weeks. For example, suppose the student must develop a classroom project within an academic course or space. The project is divided into phases so that the results of the previous phase become inputs for the next phase. A committed student receives the teacher's comments about the partial work carried out, reflects on the adjustments that must be made, and quickly initiates improvement actions, in order to achieve the proposed learning results.
- A choice of $K(s) = K_2 = 0.6K_1$ represents a student who is a bit more passive or inactive, so although he responds to comments about his work, his response is relatively small, and his reflection processes are slow. Therefore, it is not surprising that convergence towards full understanding is relatively slow. Continuing with the example of the classroom project, in this case the student receives the teacher's comments, but the reflection process is not adequate. Therefore, the observations are not fully taken into account or with the speed that is required to continue with the following phases of the project. For this reason, the project very possibly presents delays for its total completion.

- The choice of $K(s) = K_3 = 1.5$ represents the student who has an immediate response to any information, but without continuous reflection. As a consequence, although there is relatively rapid learning at the beginning, there is no convergence towards full understanding. For the example of the classroom project, it would be a student who receives the teacher's comments, but does not carry out a reflection process, but simply responds quickly to them. Thus, despite the fact that the project phases are completed within the established times, the learning results achieved are not as expected.
- The choice of $K(s) = K_4 = 0.5/s$ represents a student who does not have an immediate reaction but who undertakes a reflection. Consequently, learning is slow on the transient, but eventually masters the material. Continuing with the example of the classroom project, here the student receives the teacher's comments, reflects appropriately about them, but does not react quickly to them. This causes learning outcomes to be achieved very slowly.
- Finally, the choice of $K(s) = e^{-2s}K_1$ represents a student who ignores the teacher's comments until a later review period (here the delay is only 2 weeks). Clearly learning is slow and chaotic from then on. To finish with the example of the classroom project, in this case the student receives the comments from the teacher, but both the process of reflection about them, as well as the speed of response are carried out late. It is clear that the delay in taking action by the student greatly impairs the learning achieved.

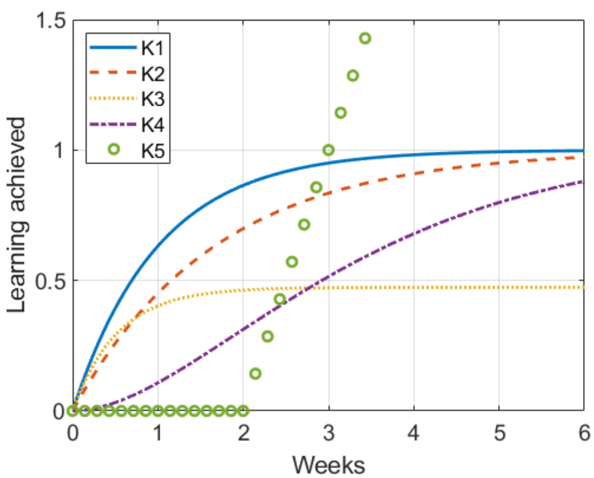

Fig. 4. Impact of $K(s)$ on learning.

This example shows that the teacher providing detailed feedback and grading students' work is not enough. This only becomes feedback when the students actively participate and thereby change their future actions. For many students there is a lack of feedback during their studies, while the teacher can provide evidence that adequate and timely feedback has been provided. An obvious conclusion is that students are not using the information provided appropriately and therefore, the feedback loop is not closed due to inactivity of the students, perhaps due to a lack of clear guidance from the teacher.

B. *Impact of H(s) on Learning*

This section will assume that all students are perfect and conscientious, that is $K(s) = (s + 1) / 0.6s$, so they are fully and quickly involved with teacher comments. The following options represent the impact of the different levels of support or quality of the comments provided by the teacher in the formative work. For the analogy to work, it must be taken into account that incomplete comments by the teacher are represented by gains greater than one in $H(s)$, this indicates an overemphasis on only some aspects of the results presented by the student and therefore, implicitly, some parts have been ignored. The way in which the level of understanding or learning evolves for each case is presented in Fig. 5:

- If $H(s) = H_1 = 1$, i.e., with perfect and immediate comments, then learning is relatively fast and converges towards full understanding. For example, when it is intended to develop a classroom project and the teacher generates very complete comments on the partial work delivered by the students. Likewise, the teacher's comments are generated quickly, which allows the learning results to be fully achieved.
- When $H(s) = H_2 = 1.5$, that is, with quick but incomplete comments, then students learn quickly at the beginning but do not converge towards full understanding. This usually occurs when students ask questions in class, or when software tools are used to self-assess learning. For example, questionnaires with multiple-choice questions with only one answer, which do not give students complete comments about why the selected answer is correct or incorrect. In this case, although the comments are generated quickly, they lack the arguments that allow students to reach a higher level of learning.
- When the teacher's comments are gradual but complete, this is represented by $H(s) = H_3 = 1/(s+1)$. Here, students converge towards full understanding, but they can do so quite slowly compared to H_1 and with unpredictable transients in their understanding in the meantime. Returning to the example of the classroom project, the teacher can generate comments with sufficient arguments for students to adjust their work, but if the number of students is high, it is possible that the comments arrive gradually. In this case, students achieve learning outcomes but more slowly.
- If $H(s) = H_4 = 1.5/(s + 1)$, i.e., comments are both gradual and incomplete, then student learning is unpredictable and unlikely to converge on complete understanding. Continuing with the example of the questionnaires, if the teacher is limited only to verify if the answers are correct or incorrect, but without

generating further comments that allow students to make the pertinent adjustments for the domain of the topics, and also the process of delivery of results is done gradually, students will not achieve the expected learning outcomes.

- Finally, when comments are delayed 2 weeks (a common scenario in universities) but are complete, this can be represented by $H(s) = H_5 = e^{-2s}$, these cause unpredictable impacts on student learning that here do not converge on a reasonable time and thus the comments have been of little help. To end with an example, the case of a teacher who performs the qualification of the exams of a course can be considered. Although the teacher can generate very complete comments for each student, the delay in delivering them can generate uncertainty in the group of students and finally the comments do not contribute to achieve the proposed learning outcomes.

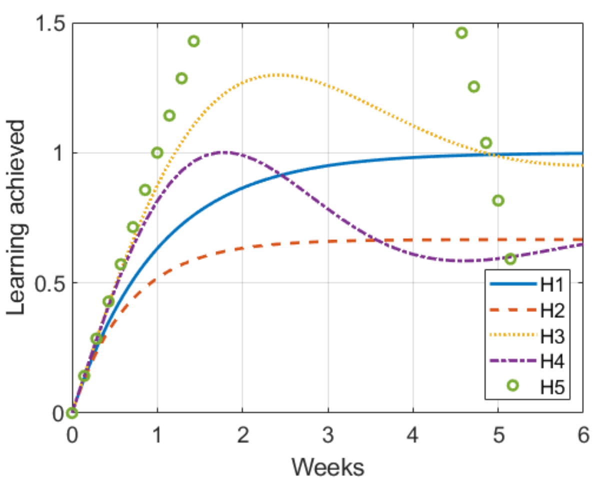

Fig. 5. Impact of $H(s)$ on learning.

This section has shown that comprehensive student learning is severely impaired by the quality and timeliness of feedback on their work and thus reinforces the idea that students should receive regular, prompt, and comprehensive feedback on their work.

III. Discussion

A key point is that although the teacher provides the feedback path, that is, comments based on the results or products of the students, it does not become feedback until the student collects and reflects about it.

Consider the situation shown in Fig. 6. In this case the quality of the comments provided by the teacher about the students' work is irrelevant because they are not making use of these comments to correct and improve their future works. This is a situation that usually is presented with typical end-of-semester exams, as students get a grade, but otherwise comments on their efforts are not exist and cannot be used effectively to improve their understanding and learning. This is not to say that end-of-semester exams do not have a role, but students must have access to feedback learning processes, that is, formative assessment, in order to prepare for them. Consequently, the feedback does not exist, although the information to facilitate the feedback does. This information cannot be converted into feedback until the student does something with it. Therefore, it's worth reviewing a common myth about feedback and making a clear statement: Feedback is not something the teacher produces, but what the student does.

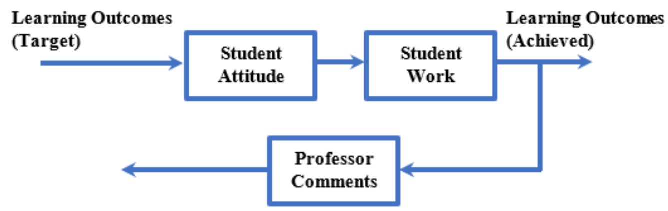

Fig. 6. Learning process without feedback.

There is no doubt that there are many ways in which attempts can be made to achieve the goal of effective feedback, as illustrated by a closed-loop control system. However, these will only be approximations to the analogy, for example, using a series of small tasks or submitting draft reports. Ultimately, the only way that such feedback can be completely effective is for students to generate and apply it themselves. Encouraging and empowering students to provide feedback on their own is an essential element in lifelong learning training and should be part of the purpose of teacher comments. Reference [5] summarizes this: in essence, feedback is sustainable when it helps students to self-control their own work independently of the teacher.

Only when students generate their own feedback, not just at the end of a task, but continuously throughout it, will effective control be available to them. As reference [11] comments: Ultimately, the fastest and most frequent feedback available is that which students give themselves from one moment to the next while studying or writing their assignments. Investing effort in developing such self-supervision can be the most profitable use of teachers' time.

IV. Conclusions

It is evident that the quality of the teacher's comments, which is what has traditionally been interpreted as feedback, has a significant impact on student learning; and any absence of these or delays in them affects learning in a detrimental way.

However, it is also clear that even with perfect feedback information, learning is significantly affected by the activity and engagement of students, that is, by the way in which they make use of the information provided. There is no benefit in grading students' work if they do not convert observations into useful feedback through appropriate reflections and actions. Ultimately, therefore, it is the action of the students that generates the feedback and determines the quality and quantity of it.

The analogy between the learning process and the control systems presented in this document shows that the role played by each of the actors in the process is key to achieving the intended learning objectives. Only through the joint commitment of students and teachers is it possible to improve the quality of teaching-learning in engineering.

ACKNOWLEDGMENT

The authors want to thank to the institutions for providing the license for the Matlab® software used in this study.

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