The Feedback Impact on Learning, A Control Systems View

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Abstract: *Learning is a dynamic process, however, most pedagogical models of learning are conceptual or static. In this paper, a first order dynamical model of learning is derived. Having the model in hand, feedback engineering from control systems perspectives was applied to analyse its impact on the process. The modelling course followed an analogy with accumulating physical processes such tank filling. The parallelism was made through supporting pedagogical and cognitive clues. The models are not a perfect mapping of reality, however, it gives an insight on the dynamical emergence of learning curves in case of unsupervised input based learning vs. constructivist feedback and reflective rich learning. Furthermore, it is argued that the models give an access to using control strategies, i.e. proportional controller, for enhancing the learning process.*

Introduction

Systems and Cybernetics can be found elsewhere in natural and engineering sciences. Control Systems methods have penetrated some social sciences, such as economics and finance. However, the methods are seldom used for quantitative and analytical analysis in pedagogy. Pedagogical processes can also be perceived in systems point of view and could be quantitatively modelled. Control systems strategies can hence be suggested for improving the process performance or directing its evolution towards a specified needed outcome. Though the absence of quantitative control systems practices in pedagogy, one can observe common language in many descriptive pedagogical papers with systems theory terminologies. Surprisingly, one can notice traces of relative consensus. To illustrate this, we will show an example of such correlation from the pedagogical literature. Juwah et al. (2004) targeted the formative assessment issue in education. They provided a conceptual model of formative feedback, and many principles of good feedback that are drawn from the model and from the research literature. Juwah refers that "formative assessment and feedback should be used to empower students as self-regulated learners"; by this, Juwah refers indeed to the necessity of adding internal feedback control loop to the student. Juwah et al. consider Sadler (1989) article as one of the strongest supporting studies of formative assessment and feedback. In that paper, Sadler explains three important factors the students should take into consideration to benefit from feedback, Juwah wrote: "The students must:1-Possess a concept of the goal/standards or reference level being aimed for. 2-Compare the actual (or current) level of performance with that goal or standard. 3-Engage in appropriate action which leads to some closure of the gap." (Juwah et al 2004). The previous three factors are nothing else but a closed feedback control loop in engineering language, as shown in Figure 1. Where "R" is the reference signal (here learning objectives for instance) given to the student (represented by the "Process" block) clearly and explicitly by the teacher as stated in factor1. The small circle represents the comparison of the performance (given as Out) and the reference (given as R), very similarly as given in the factor 2.The comparison can be achieved by the student, teacher, or peer(s). The block "Controller" represents the necessary strategies the student should take to fill the gap between the actual performance and the reference one, as stated in factor 3. Among the many principles of good practice in formative assessment and feedback, Juwah et al. list: "Facilitate the development of self assessment in learning". Under this principle they refer that the students involvement in self assessment and reflection on learning is highly effective in enhancing the learning and achievement. In control engineering, adding internal feedback control loop to the inner components of the system (here these are the student) is known as distributed control and is generally giving better results than centralized control strategies. Internal feedback loops increase the inner subsystems' robustness and give better opportunity for disturbance rejection. The principle "Delivers high quality information to students about their learning" is nothing else but having high quality measurements in the system' output which then are fed back to the input. Other pedagogical topics such as self regulated learning (Zimmerman, 2000) and instructional design (Dick and Carey, 1996), correlate significantly with control engineering from conceptual perspective. In this paper, we proceed in using control systems to model the process of learning and analyse the feedback impact.

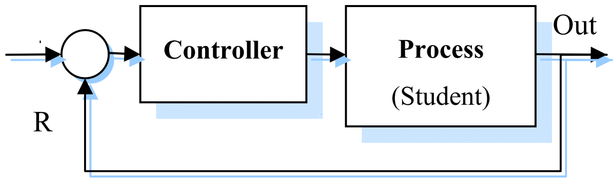

Figure 1: a feedback control systems representation to the right

Modelling Learning, Classical vs. Constructivist

Learning in principle is a dynamical process, however, most of the learning models in the pedagogical literature are static and conceptual. Dynamical models are superior because they show the transition of state over time, allow future prediction of the state status, and give an access for using controller techniques which can significantly improve the process behaviour. In this section, an investigation of modelling learning with control systems methods is shown. The teaching and learning methods can be classified under two main wide categories: (a) Teacher-centred approach, or input based learning (Classical Methods), and (b) A constructivist student-centred approach, or output based learning (Modern Methods). The teacher centred tuition is a classical approach that has been dominating until recently a shift has been initiated towards constructivism. The teacher-centred concept of learning is basically a transmitter (teacher) – receiver (student) model. The knowledge delivery in this model is mainly taking place in a form of narration, i.e. a lecture. The main assumption under this mode is that the learners will be able to assimilate the transmitted information completely in their minds once it is received. This approach emphasizes input based learning, lacking other aspects such as feedback and assessment, hence it is of open loop structure. On the other hand, constructivist pedagogy (Piaget, 1978; Brown et al., 1989; Steffe et al., 1995) perceives learning as a process of constructing knowledge by the learners themselves (Piaget, 1978; Brown et al., 1989; Steffe et al., 1995). The main pillar of the constructivist pedagogy methods is the self experience in the learning process (Kolb, 1984; Richardson, 2003). Farrell and Hesketh (2000) suggest that students typically recall about 20% of what they hear, while if they hear and see something done, they may recall closer to 50% of the experience, if they actually do something, such as conducting an experiment or solving analytical problem, they are likely to recall as much as 90%. Constructivist learning emphasize effective pedagogical practices such as assessment, feedback, and reflection (Kolb, 1984). It urges of providing the students with the whole picture, i.e. learning objectives are explicit, student-centred knowledge construction, and teachers scaffolding. The latter play rather a coordinating role. Such features conforms with a closed loop nature of learning. The positive impact of applying experiential and constructivist methods in teaching and learning can be found a large number of pedagogical research studies, examples related to engineering education are (Moor and Piergiovanni, 2003; Kamis and Topi, 2007; Bender, 2001; Plett et al, 2006; David and Wyrick, 2002).

A. Modelling Open Loop Learning

What is meant by open loop learning here is a the teacher-centred approach which does not involve assessment and feedback and is barely based on a passive transmitter-receiver model of information transfer where most of the information are delivered by the teacher. This information is thought to be fully understood and retained by the students. Apart from hearing the information, i.e. attending a classroom lecture; other important practices such as reflection, feedback, and involvement in the learning task are to large extent absent. In comparison with control systems, these are characters of open loop systems. In the classical learning model, the teacher assumes that he/she increases the students knowledge during their learning period by the fact that the students have progressively successfully accumulated the information the teacher has delivered. Such process of information accumulation can be aggregated, lumped, and modelled by an integral action. Integration is the mathematical representation of an accumulating physical phenomenon such as filling a tank or changing a capacity. In such process of integration (or accumulation), teachers accumulate knowledge progressively. The speed of accumulation or teaching (the slope of the assumed learning curve) is a factor determined by the teacher and it is the teacher's input to the process. This allows modelling the open-loop knowledge transmission during a learning period in state space form as follows:

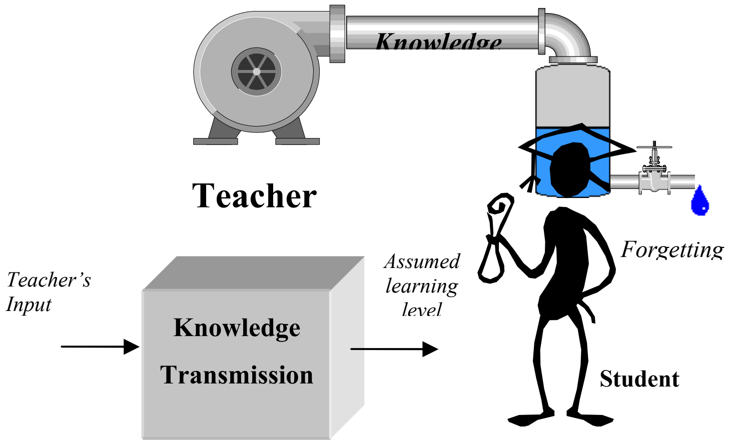

Figure 2:Open loop learning systemic model to the left and an engineering metaphor of open loop learning

$$\frac{dx}{dt} = a \times u \qquad (1)$$

where x represents the state space variable expressing the accumulated knowledge so far, u is the teacher's input determining the speed of knowledge construction (in other words, the teaching speed), a is a constant that differs from one learning task to another, this constant represents the students presumed capability to learn. Figure 2 shows a control systems of the open loop learning model together with a conceptual engineering metaphor of the process.

B. Modelling the Closed Loop Learning:

What is meant by closed loop learning here is a constructivist student-centred approach that involves the learners actively in the learning process and is distinguished with effective feedback and reflection practices. There are many characters that distinguish constructivist learning from classical approaches to learning. First of all, knowledge construction is made mainly by the learner not the teacher, i.e. student-centred approach, (Kolb, 1984; Caine and Caine, 1991; Tynjälä, 1999; Richardson, 2003). Teachers would play a coordination role during the learning process rather than a direct instructing role, they also set the whole picture to be learned (Richardson 2003, Gregen, 1995). Reflection and feedback are important characters of constructivist learning (Kolb, 1984). Mathematically speaking, the integrator (or the constructor) in this case will be the learner working on constructing the knowledge. Once the learner is given specific learning objectives (or learning trajectory) by the instructor, he/she will be working on constructing mental models mapping of the required learning objectives, i.e. learning will take place. The learner will be fed back (by self,

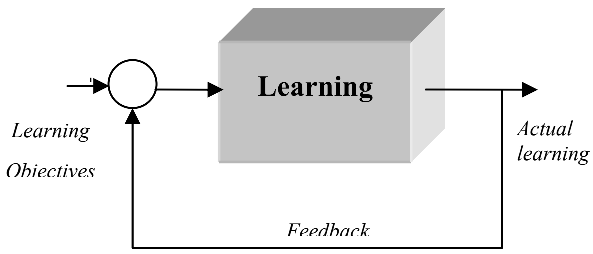

Figure 3: Closed loop learning systemic model

teacher, or peer) with information about his/her actual learning level. Hence, the learner will have an estimation of the gap between what has been actually learnt and what should be learnt. Then, the learner will continue the construction process until the actual learning level is identical to the set of learning objectives. This can be mathematically modeled as follows:

$$\frac{dx}{dt} = -a' x + r \qquad (2)$$

Where x is an internal state representing the actual learning level (already constructed knowledge), r is the learning objectives, while a' is the learning constant that may differ from one learner to another. Figure 3 shows a systemic model of the closed loop learning.

The Importance of Feedback in Learning

The importance of feedback in education has been emphasized in great number of studies. In this section, a cybernetics quantitative analysis is provided to show the advantage of introducing feedback in learning. Feedback is normally used in control systems design to enhance system performance, compensate the model uncertainties and to reject system disturbances. In a pedagogical process, feedback can be teacher-centred, i.e. it is performed by the teacher to inform the student about his current knowledge level, or student-centred, i.e. the student has self awareness of his current level and what is assumed to achieve, or hybrid, i.e. multiple feedback loops are achieved by the teacher and the student, which will lead for more robust performance. Feedback can also be provided by peers, learning technologies, or educational software.

C. Analysing The Open Loop Learning:

Let us assume that the actual learning ability (accumulating knowledge, or achieving progress) for one student is about 30% weaker than the presumed average of the class, i.e. the constant a is less by 30%. Then there will be 30% less progress in the knowledge transmission process. Simulations are shown Figure 5 for a weak vs. normal student assumed knowledge transfer, the required knowledge is 1 unit which needs 2 time units. The uncertain model can be written as follows:

$$\frac{dx}{dt} = a(1+\Delta)\times u \qquad (3)$$

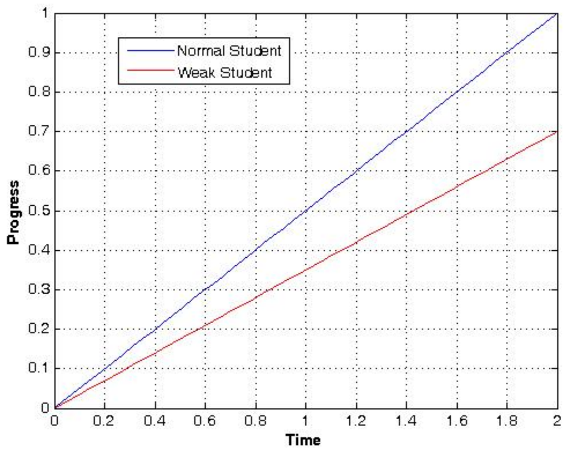

Figure 4: Simulation of open learning, weak vs. normal.

This could leave a negative impact on the student's self confidence and his motivation towards learning among his peers. The previous simulation clearly shows the weak robustness features of open loop accumulating processes. The Robustness issue is very important in the pedagogical process, where students are coming from different backgrounds, each has his/her own learning style, own learning capability, and own surrounding environment during the learning period. Hence, it is very likely that the presumed teacher model of students learning will be significantly different from one student to another. Constructivist pedagogy emphasizes the importance of taking into consideration differences among students during the learning process and accommodating these differences. This will require greater effort of the teacher to meet this important demand. One cure of this dilemma is to develop pedagogical methodologies that can compensate the differences among students during learning and at the same time does not demand larger teaching time. *From control systems perspectives, FEEDBACK represents the magical solution for managing the uncertainty weak robustness character of open loop accumulating processes.*

D. Analysing The Closed Loop Learning:

The closed feedback loop shown in Figure 3 and modelled by (2) has an inherent robustness characteristic against model uncertainty. The uncertain model version of system given by (2) can be written as follows:

$$\frac{dx}{dt} = -a'(x + \Delta x) + r \quad (4)$$

Where Δx represent the uncertainty. Now, lets consider the last case of simulating 50% weaker student than the normal (compared with 30% in the previous section). The simulation presented in Figure 5 shows very close achievement of weak and normal students when there is effective feedback practices compared with 30% less achievement in the open loop case (will be 50% less in case of 50% weaker student in the open loop learning settings). Having a bit more time than the presumed 2 times unit, the weaker student will reach the 2 units learning objective eventually. In comparison with the previous section, the 30% weaker student achieved only 50% of the required level by the end of the learning duration.

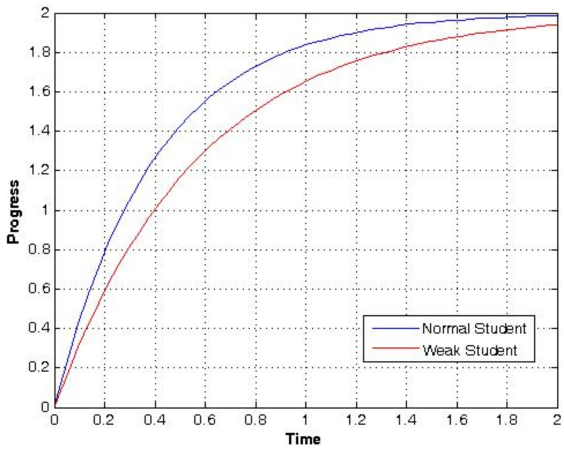

Figure 5: Simulation of a closed loop learning, weak vs. normal.

Conclusions

The models developed in this article are simplified perception of learning. Learning is rather more complex process, not necessarily to have a dominant linear mode, and is affected by many factors (disturbances or noise in control engineering terms). However, in this thesis, we follow the modelling course in control engineering were many aspects are neglected and linear behaviour assumptions are posed even when the process is obviously nonlinear. In modelling, we consider the most important aspect that the model is trying to analyse neglecting the other system characters. These main guidelines have proved to be successful in modelling technical control systems, in many times due to the nature of feedback loops which can accommodate model uncertainties. We draw on these principles when the learning modelling has been targeted in this article, hence, simplifying and aggregating many characters into a simpler linear character. The models showed the feedback effectiveness on the learning process, furthermore, we argue, that with such models controller strategies can be investigated and posed for simulations.

References

Bender B, 2001. Concepts for Purposive and Motivational Teaching and Learning in Engineering Design Courses. Int. J. Eng. Ed.17(4-5), 336-341.

Brown S, Collins A, Duguid P, 1989. Situated Cognition and the Culture of Learning. Educational Research 18, 32-42.

Caine RN and Caine G, 1991. Making Connections: Teaching and the Human Brain, Addison-Wesley.

David A, Wyrick PE, and Hilsen L, 2002. Using Kolb's Cycle to Round Out Learning. Proc. of the American Society for Engineering Education Annual Conference

Dick, W., & Carey, L. (1996). The systematic design of instruction (4th ed.). NY: Harper Collins College Publishers.

Farrell S, Hesketh, RP, 2000. An Inductive Approach to Teaching Heat and Mass Transfer. Proceedings of the American Society for Engineering Education Annual Conference & Exposition.

Goodwin GC, Graebe SF, 2001. Control System Design, Prentice Hall.

Gergen KJ, 1995. Social construction and the educational process. In P. Stele, & J. Gale, Constructivism in education (pp. 17-39). Hillsdale, NJ: Erlbaum.

Juwah C, Macfarlane-Dick D, Matthew B, Nicol D, Ross D, and Smith B, 2004. Enhancing student learning through effective formative feedback. The Higher Education Academy Generic Centre - June.

Kamis A and Topi H, 2007. Network Subnetting: an Instance of Technical Problem Solving in Kolb's Experiential Learning Cycle. Hawaii International Conference on System Sciences.

Kolb DA, 1984. Experiential learning: experience as the source of learning and development. Prentice-Hall.

Moor S and Piergiovanni P, 2003. Experiments in the Classroom, Examples of Inductive Learning with Classroom-Friendly Laboratory Kits. Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition.

Piaget J, 1978. The Development of Thought: Equilibration of Cognitive Structures. Blackwell.

Plett GL, Ziemer RE, Ciletti MD, Dandapani R, Kalkur T, and Wickert MA, 2006. Experiences in Updating the ECE Curriculum with Signal Processing First and Kolb/4MAT Pedagogy. Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Chicago, IL, June 18-21.

Richardson V, 2003. Constructivist Pedagogy. The Teachers College Record.

Sadler, DR, 1989. Formative assessment and the design of instructional systems. Instructional Science 18, 119–144.

Steffe LP and Gale JE, 1995. Constructivism in Education. Lawrence Erlbaum Associates Inc.

Tynjälä P, 1999. Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. International Journal of Educational Research 31(5), 357–442.

Yorke M, 2003. Formative assessment in higher education: Moves towards theory and the enhancement of pedagogic practice. Higher Education 45 (4), 477–501.

Zimmerman, B. J, 2000. Attainment of self-regulation: A social cognitive perspective. In M. Boekaerts, P. Pintrich, & M. Zeidner (Eds.), Handbook of self-regulation, research, and applications (pp. 13–39). Orlando, FL: Academic Press.