Performance-Related Feedback: The Hallmark of Efficient Instruction

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Performance-related Feedback: The Hallmark of Efficient Instruction

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Abstract

Performance-related feedback is feedback connected to some action that suggests to a learner something about the success of their action. Performance-related feedback is described as a definable and measurable entity. Prior research has not controlled for performance-related feedback. We suspect that, in essentially all cases where one teaching strategy surpasses another in effectiveness, it also is characterized by having more performance-related feedback. This paper reviews prior literature and steps the reader through arguments supporting the use of this construct. Performance-related feedback is a construct that is very useful to teachers and researchers, and is at the same time easily understood in terms of connectionist theories of learning.

Introduction

Most readers of *This Journal* have extensive scientific training. In science, we learn about experimentation min which we control variables. Experiences scientists will often indicate just how difficult it is to decide which variables are important and need to be controlled. This article deals with feedback, and especially feedback connected to some action made by a learner. It is quite surprising that, in most of the teaching literature, the amount of feedback a learner receives is *not* controlled. While novel, our arguments are based upon rereading a very large and well-established literature. We will present arguments intended to help both chemistry teachers and chemistry education researchers improve instruction and improve research in the study of instruction. The summary of our arguments is this: Performance-related feedback is the hallmark of efficient instruction

Mason and Bruning reviewed the literature with respect to feedback within computer assisted instruction (1). This review is quite useful for teachers interested in examining issues related to feedback such as task complexity, timing of feedback, prior knowledge, and learner control. While the review makes a variety of suggestions about providing feedback, it fails to make the most essential point: *successful instruction nearly always includes performance-related feedback*.

Tutoring is widely held to be the “gold standard” with respect to instruction. Bloom points out that, when compared conventional small group instruction typical of classrooms, tutored students perform at a level about 2 standard deviations higher (2). Because of their interest in developing automatic tutoring systems, Graesser and colleagues have studied tutoring in some detail (3). For example, with respect to questions asked in an undergraduate course in research methods, the average number of student questions asked per hour conventional instruction was 3.0. This compares with tutoring sessions of comparable length, wherein students ask 21.1 questions and tutors ask 117.2 questions on the average. In other words, *best* instruction provides learners with much more feedback than does conventional instruction.

It is generally agreed that students construct their own knowledge. One "ism" that addresses knowledge construction is called *connectionism* (4). Another is *constructivism* (5). Connectionism requires that some performance-related feedback be provide. Connectionism suggests that learners modify the way they process information based upon the feedback they receive in their environment. While this feedback may come from interactions with objects, it also may come from experts (teachers, parents, older siblings, knowledgeable friends, or others). Supporting evidence for the connectionist model is very strong, especially for language learning in infants and young children (for example, see Moerk](6, 7)).

Computer can successfully model much human development, especially with respect to such things as language learning (8). To teach a computer, one gives it performance-related feedback. It may take 20,000 feedback sessions to observe behavior from a computer that 5 or 6 sessions will bring about in a 2-year old child. These days, however, 20,000 feedback instances can be provided to a computer in seconds.

Using just exposure to examples followed quickly by feedback, Kellman has observed some striking improvements in learning to perceive and classify patterns. Training times for reading dial displays in airplane cockpits are greatly reduced (9). In describing this work, the authors state: "…Discovery in the learning of structure is a process of filtering which of the possible details, patterns, and relationships are relevant to a particular task or goal. … This learning process advances when the subject makes rapid classifications and receives *feedback* (emphasis added) over many short trials…"Performance in detecting molecular geometries is greatly enhanced using this strategy (10). Chapman reported remarkable gains in teaching introductory organic chemistry students how to determine molecular structures from nmr spectra when the strategy was employed (11).

It is more or less a given today that human thinking is centered in the organ we call the brain. Edelman (12) sets forth a comprehensive model for how the brain works. Crick (13) addresses the notion of consciousness. Examples of how contemporary scientists attempt to tie cognitive processes to brain function abound in the literature (14). Brain-based theories are not of much use to chemistry education researchers, however. The ties between human performance and brain function are far too poorly understood to make this a useful approach to improving instruction (15). It is quite clear, however, that human learning involves changing wiring – perhaps not so much by making new connections as by changing the relative importance of existing connections. In this very concrete and real sense, then learners actually do "construct their own knowledge."

Teaching strategies based upon constructivism tend to be inquiry oriented. Learners are encouraged to discover rules without a great deal of specific instructor input. Inquiry strategies often include tasks explicitly aimed at uncovering misconceptions. Teaching strategies advocated by constructivists also are advocated within the learning standards of many national groups. Supporting evidence for the efficacy of constructivist strategies is quite thin, however (16). These authors note:

> "It was found that the cognitive activities involved in successful interventions do not have to coincide with those of the goal task of science problem solving. Studying worked examples or concept mapping may also contribute to the mastery of science problem solving. The important aspect of these activities is that they stimulate the development of the knowledge base and thinking skills."

It is especially unusual for researchers to detect the effects of constructivist strategies by the end of the next sequential course in a curriculum. By contrast, content mastery strategies like Keller Plan often report gains sustained over several courses (2, 17-20). Explicit teaching of metacognitive strategies also fares well over time, with benefits seemingly long lasting (XXXX Gregg??).

In coming to present understandings of instructional design in science education, advocates who base their work upon Jean Piaget have had great influence. More specifically, many describe their understanding of child development using arguments and notions ascribed to Piaget. As yet, contemporary specialists in child development have had little impact upon the thinking of science educators. This might explain the great emphasis placed upon self-directed inquiry and low emphasis upon feedback from adults (experts) among the currently recommended strategies for teaching science.

Our Purpose

In this article we make two assertions:

- Instruction is successful when we provide performance-related feedback. Most often it comes from experts like teachers. This feedback can come from natural sources (experimentation, as in much inquiry) or from within. Excellent instruction involves a blend of strategies, *but with emphasis on feedback*; and
- Science education has reached its current juncture partly because instructional experiments have not controlled for performance-related feedback. When tested for efficacy, inquiry strategies with large performance-related feedback components often are compared with more traditional strategies with little performance-related feedback.

The first assertion provides an overarching instructional strategy that can be implemented widely by chemistry teachers. It is a more specific guideline than usually described by constructivist strategists. It does not demand that all instruction include inquiry, nor does it preclude inquiry as a potentially effective strategy. It helps explain the established success of using worked-out examples (21). It readily explains the positive learning gains often encountered with cooperative learning (22).

The second assertion is needed because science education is at a different place in time today than would be suggested by the first assertion. It is good to try to see how we got to where we are today, and to make sure that the approach advocated here does consider most of the *data* available about learning.

The reason that focusing on systematic measures of performance-related feedback makes sense in chemistry education is that the model accounts well for *more* data about leaning than competing models seem to. This model blends very well with understood neurological principles related to learning. Finally, computers can emulate the model.

Science Education Today

Science Educators Discover Jean Piaget

Jean Piaget espoused models for development (23). He suggested that humans develop through a series of stages, the last of which involves being able to apply formal (abstract) operations in a holistic way. Piaget held that the stages were developmental in nature. Though an over-interpretation on the part of many, the implication has been that it might be as hard to teach formal operations to a child as it would be to teach a caterpillar to fly.

We science teachers really do believe that we have appropriate views of the physical world. To change a student's inappropriate view of the world, teachers often believe that we need to confront that student with a situation involving some conflict. This is the basis of the teaching strategy called 'discrepant events.' Piaget called this creating disequilibrium.

In the United States, Robert Karplus (24) was a proponent of Piaget's ideas. Karplus' work has been carried on by Fuller (25) and Lawson (26). Heron (27) wrote a powerful and much cited article for *this Journal*, "Piaget for Chemists." Much of the work of Piaget and his students was based upon studies of small numbers of persons. Movies made by Karplus (28) and videotapes made by Campbell (29) showed investigators asking learners to explain certain phenomena. A learner's responses often fell into one of the stages – concrete or formal -- described by Piaget.

If the reader has children spaced by a few years and has tried a "Piagetian activity" such as pouring water from one cup to another when one child was, say, five and the other eight, then you nearly certainly have compelling, first-hand confirmation of Piaget's ideas. In describing the actions, the younger child would say that the amount of poured water had changed, while the older one would say that changing the container did not change the amount. Based upon this, the older child would be described as capable of concrete operations; the younger childe would not. The data are consistent and reproducible; an interpretation in terms of sequential stages is not nuts.

Developmental Psychologists Use Television

At about the same time as American science educators were discovering Piaget, videotape recorders were flooding the United States. There was a period during which tape recorder sales exceeded one million units per month for many successive months. It is not at all surprising, therefore, that videotapes would be used to study child development. Videotapes did for child development what Edgerton's stroboscopic photography did for the study of rapid macroscopic physical phenomena (like drop spattering) (30).

The work of the developmental psychologists is well described by Hopnik *et al.* in *The Scientist in the Crib* (31). Clearly, children are born processing. ***They inquire about their world immediately upon birth, and they receive feedback.***

Some observations of early life are truly remarkable. Consider, for example, infants learning English versus those learning Japanese. The English language has two sounds, “r” as in rice or rake and “l” as in lice or lake. Native speakers of English readily distinguish these sounds. We are told that there are no such sounds in Japanese. All infants can distinguish these sounds at birth. At 12 months, infants learning in English continue to distinguish these sounds, while those learning in Japanese do not or can not (32).

With respect to infancy, the understandings of contemporary developmentalists are much more compelling than are those of Piaget. Piaget thought infants were born with only reflexes, and that cortical processing was something acquired after birth. Clearly, Piaget underestimated newborn infants.

Seeking Explanation as Instinctive

Both Piaget and contemporary developmental psychologists share a key notion: the quest for explanation as very much a ‘human’ thing. That’s what we humans do; we try to explain things. Piaget asserts that changes are most likely to come about when the learner experiences disequilibrium, a circumstance where the predicted outcome of some ‘experiment’ is at odds with the outcome at first predicted by the learner.

Explanation is very much a part of the view of developmentalists. Indeed, they see infants as responding with measured incredulity when some aspect of their world does not seem right. For example, when a moving object is hidden by a screen, infants expect the object to emerge at a time predicted by the object’s speed. Should the object appear too soon , or not soon enough, consternation results. If the object is changed to some other object, however, that seems to be accepted (33).

Principal Differences

Two features stand out as the principal differences between Piagetian and developmentalist notions:

- The Piagetian stages might be described as a continuum by developmentalists, and
- While disequilibrium often plays a role, learning comes about through performance-related feedback. Over one's lifetime, this feedback is nearly continuous.

It is very clear that, whether training an infant by speaking 'baby talk' to acquaint it with the vowel sounds of its language (34), or by feeding 0's or 1's in response to the outputs of a computer-based neural network, feedback is critical to learning. The child seeks feedback for some not easily described biological reason. The computer gets feedback because we designed it that way.

It is remarkable that neural nets learning language can behave very much like children learning language. After numerous instances of feedback in which the outputs do not change, there are sudden dramatic bursts of apparent learning. It is as if the neural nets are going through stages. All they need to do this is feedback, but lots of it (8). In other words, intellectual growth spurts in neural nets – perhaps what we might call the transition from concrete to formal thinking in a particular area for children – result from continuous, linear feedback.

Performance-related Feedback

Feedback might be connected with falling off while learning to bike, or sensory observation when a prediction about the world goes awry (as in viewing a discrepant event). Performance-related feedback might involve looking at an answer key immediately after an exam, or hearing a lecturer present a brief explanation after an in-class question activity. It is possible to make extensive use of performance-related feedback in researchable settings, even to the degree if providing feedback to vicarious performances – situations in which the learner responds to him/herself, but in which there is no measurable, verifiable observable behavior upon which to base feedback.

The indicators for *good research* enumerated by the ACS Task Force Report on Chemical Education Research include: "the research must be theory based; the questions asked should be relevant to chemical educators and able to be tested through the experimental design proposed; the data collected must be verifiable; and the results must be generalizable." (35). Performance-related feedback provides a directly measurable base. It is less easily connected to its underpinnings in neurological models, even is better connected than any others.

But *this Journal* is not about research in chemistry education so much as it is about informed practice. For that reason, we devote the remained of the article to explicit suggestions about teaching.

Testing

Nothing gives performance-related feedback better than does testing. Frequent testing is valuable. Frequent testing is at the heart of the Keller Plan. We have long argued for repeatable testing (36). That is, we see the success of Keller Plan or PSI strategies as being in the repeatable testing. Unlike other strategies, the effects of Keller Plan courses often can be seen two or three semesters after the course ends (19, 20, 37).

Swanson concludes that dynamic assessment, a procedure that involves providing feedback to an examinee, leads to improves testing performance as compared with 'static' assessment (38).

In Class Pair Discussion

Having lecture room students work in pairs for 120-180 seconds to formulate and discuss a response to a teacher-presented question, after which time all pairs vote and the teacher gives and discusses the accepted answer, if any, provides substantial opportunity for learning. During the discussion, both members of the pair can perform and evaluate each other's performances. Having the lecturer provide a summation gives still more feedback. This strategy can require processing that is much deeper than, say, just taking notes. We recommend that lecturers following this approach include at least some of the items discussed on tests that count. So, if a lecturer uses the strategy, say, 5-7 times each week, then using 1-2 items on a major test given every three or four weeks will increases attention given to these questions.

Cooperative Learning

Cooperative learning, once much more widely advocated than it is today, involves students working in small groups. Within these groups, learners engage in activities where they provide feedback for one another about their work. Research results suggest that using this strategy improves learning by 0.25-0.5 standard deviations (meta-analysis ref.). It is quite clear than any results of cooperative learning can be interpreted in terms of performance-related feedback. That increased feedback is involved relative to conventional instruction is obvious. In best case examples, such as those of Brown (39), the nature of the feedback that the learners are expected to provide one another is very well defined and controlled.

Worked Out Examples

Schaum's Outline Series are a tribute to the success students' have found for worked out examples (22). Pressley reviews this strategy favorably (40). van Merrienboer compares three strategies for teaching the creation of computer programs: projects, theory followed by one or two examples, or numerous examples (41-43). In terms of being able to write complex, similar programs (transfer of learning), seeing numerous examples is the most effective strategy, while projects are least effective. The authors interpret this in terms of a construct called cognitive load. We suspect that the amount of feedback received is even more important. When a student sees nothing but codes for programs that work, the amount of feedback is enormous. Providing worked out examples is an area extremely amenable to the application of modern technologic tools (44).

Inquiry versus Guided Inquiry; Scaffolding

Inquiry is a tough business. To make inquiry work in real teaching settings, a strategy called guided inquiry (guided design) is employed (45). Guided inquiries provide structure. In the instructional program cited, "critical thinking questions" are employed, and instructors move from group to group. "This provides an opportunity for feedback to the group and for catching any confusion or misunderstanding that may have been missed during class. … Occasionally a question may be posed to one of the group members to make sure that he or she understands a concept or to elicit a verbal explanation of an answer which may be correct."

Projects; Research

You would be correct in your suspicion that the authors believe that teaching via projects and research is inefficient. The world does not come to us neatly bundled and labeled with readily understood rules. Knowledge about thinking and reasoning has grown, as has knowledge about neural computer systems and human neurophysiology (15). We believe that this article points to a very serious question for readers to ponder: have chemistry teachers thought appropriately about performance-related feedback? When could and should this article have been written? As time goes on from here, we expect to see numerous formal tests of this notion. It may aid our thinking about teaching and lead to improvements in chemistry teaching.

If we stumble along as we try to improve ourselves as chemistry teachers, why shouldn't we have our students stumble along, too? While engaging students in projects and research almost certainly is inefficient, it is at the same time the truest measure of what we do as scientists.

Related Issues

Lecture; Lecture Notes

In college science courses, we lecture. In many high school chemistry courses, we lecture. Lecturing is an instructional strategy wherein performance-related feedback is just about non-existent. While perhaps better than no notes in a situation where the lecturer lectures, most of the feedback that comes from creating notes is internal – a combination of tactile and visual feedback. While better than none at all, this feedback is minimal. There is no external evaluation of the performance.

There is a metacognitive strategy called self-explanation (46). It is possible that a learner attending a lecture experiences self-explanation, and this is effective in learning. Self-explanation is not automatic; students become more successful with this strategy after both explicit instruction about the strategy and feedback about their success in the early stages of using the strategy. In a study related to teaching LISP programming, Brown showed that explicit instruction in self-explanation led to large improvements in learning (47).

Matching Learners with Feedback

Feedback must be given in a form that is useful. Giving adult speakers of Japanese ordinary feedback about "r" and "l" sounds has proven useless. This problem is likely to be very close to the speaker's feature detectors and may not even be addressable for many adults.

It makes as little sense to give feedback that is cognitively mismatched. Elsewhere we discuss the importance of prior learning in predicting the success of current learning (48).

While a full discussion of this topic is better suited for a different article, the notion of *cognitive load* mentioned earlier is worth discussing. Many experiments suggest that our ability to process information is a function of available *working memory*. In working memory, we can keep track of about five items or chunks at a time. Because the size of a chunk can grow with learning and experience, the complexity of the tasks we can undertake successfully also can grow (49). Cognitive load is a measure of how much a task utilizes working memory. Johnstone has discussed this concept as it applies in chemistry education (50).

Cognitive load has been the basis of analysis in the very large strategy comparison literature developed largely by Sweller and his students (51).

Active Learning

Because we are connectionists at heart, we've focused upon performance-related feedback. Better known, however, is a vague construct called *active learning* that has emerged in the education literature (52). This construct implies that active learners are somehow mentally engaged in learning. A learner engaged in the exploration phase of a three phase Piagetian learning cycle (53) would necessarily be an active learner. Active learning is most often described by example. A minimally active learning strategy in a traditional lecture might involve the learner taking notes. Lecture learning that is still more active might involve having lecture room students work in pairs to discuss and formulate responses to a teacher-presented question.

The intent and the degree of active learning need not be related. Attending lecture is not usually intended as an active learning strategy, yet a learner engaged in self-questioning during lecture might be very "active"– even if his/her performances are not observed and provided with specific feedback. A pair of learners tasked with responding to a lecturer's question might instead discuss an athletic event or concert – being entirely off task and disengaged.

Some of the difficulty has to do with perceptions about early work on mastery learning, which many felt to be quite 'mindless.' To learn difficult material, one needs to put forth something well described to most readers by the term mental effort. Physics educators have developed a tool for measuring student understanding of forces using an instrument, the *Force Concept Inventory*. In a study involving over 60 programs and many students, Hake (54) concludes that instruction using interactive engagement is especially effective at enhancing student understanding as measured by this instrument:

> "… those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors, all as judged by their literature descriptions"

Among the strategies explicitly recommended by Hake is the use of MBL experiments. Royuk recently showed that, when embedded within "cookbook" experiments, MBL activities were much less effective than when embedded within interactive lessons that afforded considerable feedback (55).

If you go with active learning, it is very difficult to see how to prepare teachers in methods classes or perform research. On the other hand, it is easy to teach teachers about providing performance-related feedback. Moreover, performance-related feedback is a useful construct researchable settings. Even vicarious performances – situations in which the learner responds to him/herself, but in which there is no measurable, verifiable observable behavior upon which to base feedback – can be studied. In a simple research design, half of a class can be instructed to respond in some measurable way, and the other half to respond vicariously. Learners can self-assess as to the degree of their participation in vicarious activities and thereby give researchers some measure. Learners also could be interrupted to make explicit an otherwise vicarious act. Perhaps most important, performance-related feedback is something that can be controlled in research settings. It has *not* been controlled in much prior research.

Conclusion

When teaching difficult material in chemistry, we often struggle with strategies to improve our students' success. When designing or redesigning instruction, reasonable, justifiable questions to ask oneself are 'how much performance does the student make' and 'how much feedback do I give them about that performance.' As the term difficult already implies, some content is hard to handle for most learners. Nearly anyone can teach easy content, and nearly anyone can learn easy content. It is when the content gets difficult that you have to think about instruction. Our reinterpretation of a great deal of literature suggests that increasing the amount of performance-related feedback is one of the most effective ways to improve instruction.

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