Improving Chemistry Teaching Using an Interactive, Compensatory Model of Learning

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Abstract

Many college chemistry teachers have little or no formal training in education. When issues related to education are discussed, these teachers are confronted with an array of apparently conflicting information, practices, and ideas. A speculative model, the *Interactive Compensatory Model of Learning*, is based upon a synthesis of the very diverse education research literature. It conceptually unifies seemingly conflicting elements. The model suggests: a) many skills make important contributions to learning; b) no single skill can support totally or interfere with self-regulated learning; c) effective learning depends on the dynamic interrelationship among existing knowledge including a variety of learning skills; d) it is possible for most learners to compensate for weaknesses in one area using strengths in other areas; and e) it is possible to improve skills through classroom instruction. This paper describes the model and provides practical suggestions. A companion Web paper provides details.

Key Words:

Chemical Education Research (CER); Teaching/Learning Aids

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The Interactive Compensatory Model

The purpose of the interactive compensatory model of learning (ICML) is *to provide a* ***framework*** *for understanding and improving teacher skills in creating learning environments*. Though speculative, the model is consistent with a wide variety of empirical data. What follows is a brief description of our model followed by practical suggestions for all chemistry teachers grounded in the theory supporting the model. Our intent is not to provide a literature review, but to outline a research supported way of understanding learning and to use this to generate some practical suggestions. A detailed description of the model, including empirical support, can be found on-line *(1)*.

The ICML includes five main components: cognitive abilities, an organized knowledge base, strategies, metacognition, and motivational beliefs (Figure 1). Cognitive abilities refer to one's general capacity to learn (intelligence). The knowledge base refers to organized, domain-specific knowledge and general knowledge in long-term memory. Strategies refer to procedures that enable learners to solve specific problems. Metacognition includes knowledge about oneself as a learner, and how to regulate one's learning. Motivation refers to beliefs about one's ability to successfully perform a task, as well as one's goals for performing a task. Knowledge and regulatory skills such as strategies and metacognition are combined into one overarching module because of the close relationship among these three components.

Place Figure 1 about here.

We envision three interrelated modules within the model: cognitive abilities, knowledge/regulation, and motivational beliefs. Each of these modules includes a number of subcomponents. For example, the motivational beliefs module includes self-efficacy (am I up to learning this content?) and attributional beliefs (who or what is responsible for how much I learn?) *(2)*.

The numbers in Figure 1 give estimates of correlation coefficients from numerous studies relating the modules (see the companion Web paper for details). *Interestingly, the highest correlations are found for prior related knowledge!* Indeed, correlations of 0.6 (accounting for about one third of the variance) between prior knowledge and learning are among the lower reported values.

We assume that each of the modules contributes directly or indirectly to learning, and compensates for potential deficits in other components. Specifically, we assume that cognitive ability is related to learning both directly and indirectly via knowledge and regulation. Strategies and metacognition typically co-develop and are strongly related. Knowledge and regulation are related to motivation. Cognitive ability is not related to motivation. Knowledge, regulation and motivation each are related directly to learning.

One obvious oversimplification in the model is the isolation of some measurable entity we call learning. Our model assumes that, whatever learning takes place, it is integrated within the learner's components as suggested in Figure 2. In other words, one learning state, K_n is arrived at from state K_{n-1}. To go to a new state, K_{n+1}, assumes that the state K_n has been taken into the totality of previous learning.

Place Figure 2 about here.

Classroom Applications for Chemistry Teachers

Effective learning includes a number of autonomous components that compensate for each other. Each component is malleable and subject to change in the classroom. In light of the ICML, our suggestions take into consideration both the strength of the relationship between any of the variables and the potential for an instructional impact. The following section describes a number of strategies for improving four of the five components.

Improving Cognitive Ability

Debate continues as to the extent to which teachers or environmental factors such as peers or cooperative groups can change cognitive ability. Considerable debate exists over whether cognitive ability may be altered through appropriate instruction *(3)*. Virtually everyone agrees that few short-term changes are possible, even if it is possible to change ability over a longer period. Ability matters to the extent that it limits an individual's ability to acquire knowledge. Learning the typical undergraduate chemistry curriculum is more an issue of effort and persistence, not endowment. As shown in Figure 1, knowledge is a much better predictor of learning than ability *per se*.

Improving Knowledge

Classroom instruction increases knowledge, and numerous examples have been reported in this Journal (recent examples: *(4-6)*). The debate is not whether knowledge is changeable, but how to change knowledge most effectively in a limited amount of time and in ways that promote deeper conceptual understanding. Three general questions arise with respect to changing knowledge. *What kind of knowledge does one want to develop?* Factual knowledge can be changed in a matter of weeks with well-organized instruction. A broad conceptual understanding of a domain may take years to develop. Moreover, much of the knowledge possessed by an expert is often tacit rather than explicit *(7).* To become knowledgeable within a domain such as chemistry, students must possess an array of factual, procedural and conceptual knowledge *(8).*

What type of instruction best facilitates knowledge development? Most educational debates focus on three main instructional approaches: direct, socially mediated, and autonomous learning *(9).* Direct instruction includes teacher led classrooms as well as learning environments such as laboratories in which procedural knowledge is modeled for students. Socially mediated learning includes a variety of student-centered approaches such as cooperative learning in which a small group of students work together with minimal assistance from teachers *(10).* Students can and do work autonomously, independent of teachers and other students. Computer assisted instruction usually involves autonomous learning.

All three approaches can be effective and are not mutually exclusive *(8).* We advocate a blend of all three approaches. Advantages and disadvantages of each approach can be expressed in terms of important variables such as efficiency, depth of coverage, student engagement and time. Direct instruction enables teachers to convey a large body of knowledge quickly and efficiently to students. A primary advantage to direct instruction is modeling by an expert. Teachers model in many ways.

Most important, they model ways of thinking. Teachers should make every effort to make their thinking explicit to students in order to promote self-regulatory skills. Socially mediated learning helps students use knowledge to solve problems, and to modify that knowledge to fit new problems. Autonomous learning helps students reflect on new ways to apply that knowledge.

Which instructional practices best promote deeper learning and expertise? Research suggests it takes about five to ten years, or 10,000 hours, to become an 'expert' *(11,12)*! For example, training a physician from the beginning of medical school to the end of a three-year residency program takes seven years and nearly 20,000 hours. One reason expertise develops so slowly is that much of the declarative and procedural knowledge needed to master a domain is acquired tacitly over a long period *(13,14)*. Evidence suggests that much of our knowledge is acquired tacitly even when we receive a great deal of formal training in a domain *(7)*. Because of this, even highly skilled experts often find it difficult to describe what it is they know about a body of knowledge and, consequently, may be poor decision makers when forced to reflect on their knowledge *(15)*. Time is a critical variable *(16)*. Successful instructional practices for developing deep learning and expertise will both require and encourage students to remain positively engaged in material for long periods of time.

Improving Strategies and Metacognition

Strategy instruction is ideally suited for the classroom because it can be done quickly and efficiently compared to the time and effort needed to change ability and expert knowledge *(17,18)*. We distinguish between general and specific strategies. While chemistry teachers teach chemistry-specific strategies with pride and enthusiasm, they tend to avoid instruction in general strategies. General strategies usually are domain-independent heuristics and are described by terms such as help seeking, summarizing, paraphrasing, and positive self-talk.

In science, the notion of controlling variables in experiments is a general strategy, and Nobel prizes are awarded to those who discover what truly amount to new variables. In chemistry, conservation of atoms is a general principle, as exemplified by determining all components in an analytical procedure, or accounting for all of the limiting reagent after a chemical synthesis. Domain specific strategies often are very algorithmic in nature, such as when using dimensional analysis *(19)* in a stoichiometry problem, or counting four bonds to each carbon atom in an organic structure.

Pressley and Wharton-McDonald *(20)* recommend strategy instruction before, during, and after the main learning episode. Strategies that occur before learning include setting goals, determining how much information to learn, deciding how this information relates to what one already knows, and anticipating how the to-be-learned information will be used. Strategies needed during learning include identifying important information, predicting, monitoring, analyzing, and interpreting. Strategies used after learning include reviewing, organizing, and reflecting. Good strategy users possess some degree of competence in each of these areas.

It is the strategic use, rather than the mere possession of knowledge, that improves learning. Teaching strategies to students not only improves their learning but also increases their self-efficacy. Compare the most and least successful students in each class. The chances are good that highly successful students rely on strategies that struggling students do not use. Modeled instruction with these strategies should enhance students' ability to regulate their learning. Most important, give them opportunities to practice, and give them feedback about their practice.

Improving Motivation

Many studies suggest that motivational beliefs are malleable *(21,22)*. Changes occur for several reasons including student awareness, teacher modeling of adaptive beliefs, and changes in classroom processes such as evaluation and grading. Here are some ways to change self-efficacy and goal orientations.

Self-efficacy refers to the degree to which a student feels capable of achieving a specific goal. Self-efficacy is affected by self-assessments, performance-based feedback, and environmental cues *(23)*. Increase students' awareness of the self-efficacy concept. Emphasize the positive consequences of high efficacy by describing how efficacy develops and deteriorates, and promote positive efficacy messages in the classroom. Peer and teacher modeling also increase self-efficacy. In many settings, peer models are most effective because they are judged to be most similar to students. Behavioral and environmental feedback are two of the most important influences on self-efficacy. Feedback is most effective when it relates performance outcomes to activities that cause those outcomes.

Previous research has distinguished between mastery and performance goals. Mastery goals are characterized by the desire to improve one's competence. Performance goals are characterized by the desire to prove one's competence. Students with mastery goal orientations are more focused on learning, demonstrate more effort, have higher levels of self-efficacy, and perform better than students with performance goal orientations *(24)*. Dweck and Leggett *(25)* suggest that goal orientations are due to attitudes about the changeability of cognitive ability. This is really important for chemistry teachers. We are thought to be teaching content that is ‘hard,’ and that access to the content is controlled by one’s ability. While this certainly is partly true, it most often is overrated. Help students develop strong mastery orientations.

A mastery goal orientation is promoted when instruction focuses on mastery learning. Mastery learning, where learners are expected to continue studying material until they are able to demonstrate that they know the material, has an excellent basis in research *(26)*. Short of tutoring or mentoring, mastery learning has the strongest research support of any known teaching strategy. Stress that mistakes are a normal (and healthy) part of learning. Everyone makes mistakes when learning something new. How teachers respond to these mistakes sends a powerful message to students. When mistakes are viewed positively, receive corrective attention, and are used to provide feedback to students, students learn more than when mistakes are viewed in a negative light *(27)*. Encourage individual rather than group evaluative standards. Group-based grading reinforces a performance goal orientation (often known to chemistry teachers as grade grubbing), given that each student is compared directly with the group norm. Encouraging uniform standards is more likely to promote the development of a mastery goal orientation.

Putting It Together

The optimal goal for a teacher is for all of the students faced with a learning task to start with the same, appropriately high level of prior learning. Mastery learning is a concept that has been around in education for several decades. Bloom, an advocate of this strategy, points out that mastery learning is one of the most effective ways to improve learning *(28)*. Many of the instructional tactics described in Bloom's book *(26)* can be interpreted in terms of the ICML model. Mastery learning was found in many Keller Plan courses of the mid-60s to mid-70s *(26,29-32)*. Recently, Peladeau and co-workers reported on a Web-based system supporting practice to mastery and over learning (trails beyond mastery) in a quantitative course. Students who engaged in learning to mastery and beyond were much more successful than those that did not *(33)*.

It is not unusual for chemistry teachers, especially college chemistry teachers, to eschew attention to motivation. Motivation interacts with knowledge, and evidence suggests that teacher attention to motivation pays off. Clearly, teachers should devote time to explicit instruction related to increasing student self-efficacy and mastery goal-orientation. This kind of instruction can be provided in parallel to traditional classroom activities such as flashy demonstrations where part of the emphasis is on students having a good time.

Summary

The purpose of this paper is to describe the Interactive Compensatory Model of Learning (ICML) and suggest its implications for chemistry classroom instruction. The model includes cognitive ability, knowledge, strategy, metacognition, and motivational components. Our claim is that each component contributes directly to learning and implies some practical suggestions for improving instruction.

Within the ICML, it is possible for most learners to compensate for weaknesses in one area using strengths in other areas. Currently, there are a number of studies supporting this view and none that we know of that refute it. As Pressley et al. *(18)*

emphasized over a decade ago, self-regulated learners use a wide variety of skills in a versatile way.

Our suggestions are general and grounded in the larger body of educational research that extends beyond chemical education. In fact, teachers of any content area could improve learning in their courses by applying our suggestions. Explicit techniques for teaching chemical problem solving are also available and should be considered as complimentary to the ICML and our suggestions *(34)*. For example, Gabel and Bunce suggest the positive impact of social interaction, explicit problem solving approaches, and the use of analogies for improving student problems solving. These are exemplars of the strategies and regulatory components described in the ICML.

It is possible to improve knowledge, strategies, metacognition, and motivation via classroom instruction. Some skills, no doubt, are more amenable to instruction than others. Nevertheless, the skills described in this paper can be changed given a supportive environment and the will to do so on the part of the student.

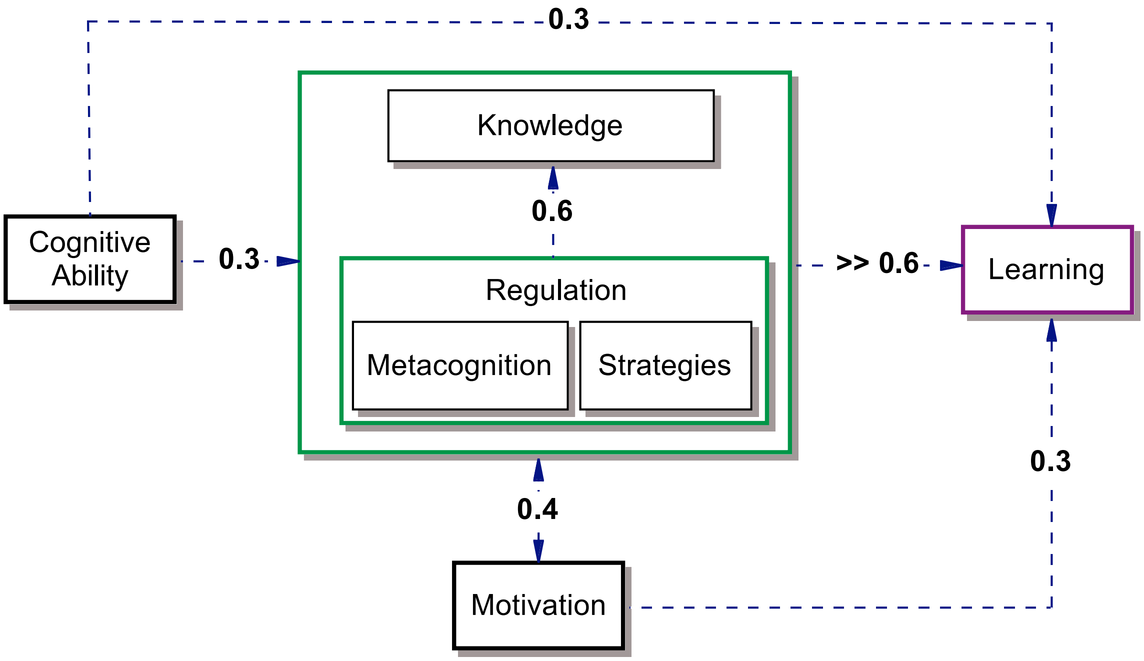

Figure 1. Interactive Compensatory Model of Learning (ICML). Decimal values indicate typical correlations between components.

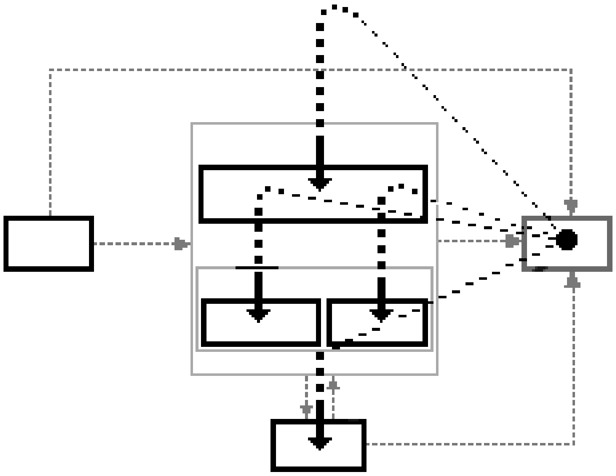

Figure 2. Learning is integrated into the Student's 'Package.'

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