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The Many Forms of Constructivism

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Introduction

Throughout our careers we face a series of choices that shape the day-to-day practices we use in the classroom, in the teaching laboratory, and, for some, in our research laboratory. These decisions are often made on the basis of prior experience, or advice from colleagues or friends, as one might expect. For many academic chemists, however, there is subtle difference between the choices they make while doing research and the choices they make in their teaching: Their research is more likely to be guided by a theoretical framework.

This paper is based on the assumption that there are a variety of theoretical frameworks that can guide instructors in their decisions about the classroom environment they build, in much the same way that there are a variety of theoretical constructs upon which research can be built. A powerful theoretical framework for educational decisions can be built on the work of Jean Piaget, which has been reviewed in the *Journal* by Herron [1,2]. Another powerful theoretical framework can be found in William Perry's book *Forms of Intellectual and Ethical Development In the College Years*,[1] which has been reviewed in the *Journal* by Finster [3,4]. A third theoretical framework is provided by the constructivist theory of knowledge.

Traditional Versus Constructivist Theories of Knowledge

It is almost 15 years since a paper on the constructivist theory of knowledge was published in the *Journal* [5] that began:

> Until recently, the accepted model for instruction was based on the hidden assumption that knowledge can be transferred intact from the mind of the teacher to the mind of the learner. ... Unfortunately, all too many of us who teach for a living

> have uncovered evidence for the following hypothesis: *Teaching and learning are not synonymous; we can teach, and teach well, without having the students learn.* [6]

To fully understand this hypothesis, it is important to distinguish between traditional theories of knowledge and constructivist theories.

Traditional theories assume that our minds contain images that somehow represent reality as if they were copies, or pictures. If one accepts this assumption, knowledge can be judged as "true" or "false." It is "true" if and only if it corresponds to reality. von Glasersfeld [7] has argued that the traditional theory searches for a match between knowledge and reality in much the same way that one might match samples of paint. If they are not the same, they must be different.

Traditional theories have shaped the way classrooms are built, the way courses are taught, and the way the students' knowledge is assessed. In many classrooms, the chairs are bolted to the floor so that the students all face the instructor, who is presumed to be the sole source of the knowledge to be learned. Although an enormous amount of time and effort are devoted to the lab, both to develop new laboratory activities and to shepherd students through the laboratory experience, [8] most of the credit in introductory chemistry courses is allocated to the lecture component of the course, during which knowledge is presumed to be transferred from the instructor to the students. Assessment is then based on exams that test whether the students have learned the material by comparing their answers with the instructor's, thereby determining whether the answers are "true" or "false."

Constructivist theories of knowledge are based on a fundamentally different assumption: *Knowledge is constructed in the mind of the learner*. These nine words, by themselves, are unlikely to strike terror in the heart of anyone who “teaches” chemistry. In fact, the opposite is often the case — they strike a responsive chord for many who remember their own struggles to understand chemistry. It is only the implications of this phrase that cause trouble because this assumption leads one inexorably along the path to a corollary assumption: *Knowledge is seldom transferred intact from the mind of the teacher to the mind of the student.* A second, more radical, form of the constructivist theory has been summarized as follows: *Useful knowledge is never transferred intact*.

The constructivist and radical constructivist theories assume that knowledge results from a more or less continual process in which it is both built and continually tested. We aren’t free to construct just any knowledge. Our knowledge must be *viable*; it must “work.” From the perspective of the constructivist and radical constructivist theories, knowledge should no longer be judged in terms of whether it is true or false, but in terms of whether it works. The only thing that matters is whether the knowledge we construct functions satisfactorily in the context in which it arises.

The author to whom correspondence should be addressed based a considerable amount of the early work in his career on the knowledge that electrons, protons, and neutrons “spin” in one of two possible directions on their axes. To this day, he isn’t all that comfortable with the notion that electrons “spin” — this seems to conflict with his understanding of the implications of the wave-particle duality of matter. All that he knows is that this knowledge “works.” It allows him to understand why ^{10}B has a nuclear spin quantum number of 3, whereas ^{11}B has a spin quantum number of 3/2, and ^{13}C is a spin 1/2 nucleus.

von Glasersfeld [7] argues that the knowledge we construct must fit reality the way a key fits a lock, which is very different from looking for a match between knowledge and reality because many keys, with slightly different shapes, can open the same lock. Polkinghorne [9] has argued that constructivist theories require a shift "from metaphors of correctness to those of utility." In other words, knowledge is no longer true or false; it either works or it does not.

It might be useful to provide an example of what we mean by the phrase: *knowledge that functions satisfactorily within the context in which it arises*. Imagine what might happen if a junior or senior chemistry major tried to explain the reactivity of acetylene to a student taking organic chemistry. The odds are good that the reactivity of acetylene would be attributed to the $C{\equiv}C$ triple bond. Suppose that later that day the same undergraduate chemistry major was tutoring a student in general chemistry who was struggling with the descriptive chemistry of nitrogen. When asked to explain why the N_2 molecule is virtually inert at room temperature, it is almost a virtual certainty that the $N{\equiv}N$ triple bond would be invoked. At the end of the day, our chemistry major would go back to his or her room feeling good about what he or she had done, without realizing that the same phenomenon — the existence of a triple bond — had been used to explain why one of a pair of isoelectronic molecules is fairly reactive and the other is chemically inert. Within the context of organic chemistry, triple bonds are a source of reactivity. Within the context of descriptive inorganic chemistry, they are a source of stability. Because so much of our knowledge is domain specific, it isn't surprising that most chemists never recognize the dichotomy between their explanations of the chemistry of acetylene and N_2.

The difference between the traditional and constructivist theories of knowledge mirrors the difference between the philosophy of science known as realist, objectivist, or positivist and the philosophy of science known as relativist [10]. Realists and relativists agree on one point: our knowledge of the world is based on the experiences of our senses. They differ, however, on their beliefs about the extent to which the world is knowable.

Realists believe that logical analysis applied to objective observations can be used to discover the truth about the world in which we live. They view knowledge in science as cumulative; it builds upon existing knowledge as science progresses. [11] They believe we can separate objective truth from our "means of knowing it." [12]. In other words, the identity of the researcher and the choice of research methodologies will have no effect on the truth that comes out of the research. Realists judge progress in science as an increasingly accurate fit between scientific theory and reality.

Relativists accept the existence of a real world, but question whether this world is "knowable." They note that observations, and the choice of observations to be made, are influenced by the beliefs, theories, hypotheses, and background of the individual who makes them. Statements about these observations are then expressed in a language whose words are embedded in a particular theoretical framework. Relativists therefore question whether a truly unbiased, objective observer can exist. (In the words of von Glasersfeld, "Objectivity is the myth that an observation can be made in the absence of an observer.") Relativists also note that the realist perspective is not consistent with the history of science [13-15].

Implications for Instruction

Constructivist theories require a subtle shift in perspective for the individual who stands in the front of the classroom. From someone who "teaches" to someone who facilitates learning; from teaching by imposition to teaching by negotiation. As Dudley Herron expressed it:

> The major influence that research in psychology and education has had on my teaching is the portion of the time I spend telling students what I think versus the portion I spend asking them what they think. [16]

Rosalind Driver [17] has argued that teachers who adopt the constructivist theory of knowledge exhibit the following behavior.

- They question students' answers, whether they are right or wrong, to make sure that the same words are being used to describe the same phenomena.
- They insist that students explain the answers they give.
- They don't allow students to use words or equations without explaining them.
- They encourage students to reflect on their answers, which is an essential part of the learning process.

Problems with the Constructivist Theory

Three objections have been raised when the authors have tried to describe the constructivist theories of knowledge to college and university faculty. Some accuse constructivists of falling into the trap of doubting whether a real world actually exists. Others argue that the constructivist theories prevent us from saying that a student is *wrong*. (They argue that it limits us to talking about “alternative concepts,” or “less-powerful concepts,” or “naive concepts,” instead of “misconcepts.”) Finally, some have argued that by concentrating on the process by which the individual learns, constructivism ignores the role of those who influence learning.

These objections can all be overcome by recognizing that most of the discussion of the constructivist or radical constructivist theories in recent years has been based on a version of these theories that can be traced back to the work of Jean Piaget and has ignored an alternative view of the construction of knowledge proposed by the clinical psychologist George Kelly.

Alternative Forms of Constructivism

Practitioners of a field that differentiates between E_i, E_1, E_2, E_1cb, E_α (1,1), and E_β (1,2) elimination reactions [18] should have no trouble accepting the notion that different forms of constructivism exist. In an editorial for the *Journal of Research in Science Teaching*, Good noted that a graduate student with whom he was working had found the term *constructivism* associated with a long list of modifiers. [19] Some order can be brought out of this apparent chaos, however, by exploring representative "forms of constructivism," [20] which focus on different aspects of the process by which knowledge is constructed.

Piagetian or Personal Constructivism

The basic form of constructivism outlined in our 1986 paper might be called personal constructivism. This approach, which emphasizes the idea that the construction of knowledge is something that is done by individuals to meet their own needs, is an outgrowth of Piaget's model of cognitive structures as a collection of "schemes" or "schema." [21]

Schema are components of an individual's general knowledge structure that relate to that individual's knowledge of the world. [22] They are triggered by an individual's perceptions of his or her environment and provide the context on which subsequent behavior is based. Schema seldom include specific information about an appropriate response to a specific situation, but they provide a structure that allows one to make inferences by including both facts about a *type of situation* and the *relationship between* *these facts*. [23] According to Piaget, “assimilation” occurs when a preexisting schema or mental structure is used to interpret sensory data for which the schema might not be appropriate. Differences between the trigger that normally activates the schema and the trigger that is assimilated to this mental structure are ignored either because no difference is perceived or because no attention is paid to the differences that are perceived. Disequilibration occurs when we cannot assimilate our experiences into preexisting schemes; equilibrium is restored by modifying these preexisting schemes by a process known as accommodation until the discrepancy is resolved [5].

To illustrate both the power and the limitations of a schema, consider the process by which one unconsciously evaluates restaurants while driving through an unfamiliar town. Certain schema are activated when one drives past a fast-food restaurant, *even if it is a chain with which one is unfamiliar*. Other schema are activated when one passes the kind of restaurant where one would stop for a leisurely meal. Still others are triggered when passing a restaurant best suited for a fancy meal. Now imagine that you were trying to select a restaurant while driving down Albany Highway in the Victoria Park section of Perth, the day after you first arrive in Australia. Stimuli would be perceived that triggered your schema for selecting restaurants, and you would do your best to assimilate your perceptions into these schemas, but your success in selecting a restaurant that meets your needs would be considerably smaller than normal.

Piaget’s model of personal constructivism serves as the basis for much of the work that has been done on conceptual change pedagogy, which involves the development of teaching/learning experiences that help students through the process of making large-scale changes in their understanding of a concept, such as the transformation required to move from an Aristotelian to a Newtonian (or from a Newtonian to a relativistic) perspective. [24] Strike and Posner, for example, have developed a model of conceptual change that builds on Piaget's focus on the role of *disequilibration* in concept formation. [25] This model is based on the following conditions.

- The student must experience a feeling of *dissatisfaction* with his or her existing conceptions that cannot be resolved by making minor changes in these conceptions. (Students are unlikely to make major conceptual changes until they believe that less radical changes will not work.)
- The new conception we expect the student to learn must be at least minimally *understood* by the student undergoing conceptual change. This individual must be able to grasp how experience can be structured by the new conception sufficiently to explore the possibilities inherent in it.
- The new conception must appear initially *plausible*. Any new conception adopted must at least appear to have the capacity to solve the problems generated by its predecessors, and to fit with other knowledge, experience, and help. Otherwise it will not appear a plausible choice.
- The new conception should appear to be *powerful* or *fruitful*. It should have the potential to be extended, to open up new areas of inquiry, and to have technological and/or explanatory power.

The example the first author has often used to illustrate the Strike-Posner model involves Avogadro's hypothesis. When he took chemistry for the first time, he thought it was absurd to assume that equal volumes of different gases contained the same number of particles. He knew intuitively that gases contained empty space, but seriously underestimated the fraction of the space that is empty. To him, and many of his contemporaries, Avogadro's hypothesis was just as counterintuitive as it was to John Dalton, who rejected Gay-Lussac's data on combining volumes for similar reasons.

Almost 15 years ago, he learned a lecture demonstration that confronts the intuitive model of gases he brought to his first chemistry course [26]. Start with a plastic 50-mL Leur-lok syringe. Pull the plunger out of the barrel until the volume reads 50 mL. Now drill a small hole through one of the veins of the plunger through which a nail can be inserted.

Push in the plunger until no gas remains in the syringe, seal the syringe with a syringe cap, pull the plunger back out of the barrel of the syringe, insert the nail into the hole in the vein of the plunger, and weigh the “empty” syringe to the nearest 0.001 grams on an analytical balance. Fill the syringe with different gases and determine the weight of 50 mL of each gas. Now use the known molar mass of each gas to calculate the number of gas particles in each sample.

Typical data obtained with this apparatus are given in Table 1. Within experimental error, the number of gas particles in each sample is the same. It might still seem strange that equal volumes of different gases contain the same number of particles, but it is no longer possible to avoid this conclusion.

Table 1

Gas	*Weight of 50 mL of gas*	*Number of particles in 50 mL*
H_2	0.005 g	1×10^{21}
N_2	0.055 g	1.2×10^{21}
O_2	0.061 g	1.2×10^{21}

Ar	0.081 g	1.2×10^{21}
CO_2	0.088 g	1.2×10^{21}
C_4H_{10}	0.111 g	1.15×10^{21}
CCl_2F_2	0.228 g	1.14×10^{21}

This demonstration can produce the *dissatisfaction* called for in the Strike-Posner model. It might also take us a long way toward the goal of making Avogadro's hypothesis *plausible*. Other arguments now have to be used to make this theory seem *powerful* or *fruitful*.

Radical Constructivism

The radical constructivist theory is associated with the work of Ernst von Glasersfeld [7, 27, 28], who has built his view of constructivism on two principles. First, knowledge is not passively received; it is actively built by the individual. Second, the goal of cognition is to organize our experiences of the world by making these experiences meaningful.

Social Constructivism

By focusing on the individual learner, the personal and radical constructivist theories seem to either neglect or ignore the ways in which social interactions influence the process by which knowledge is constructed. One of the best introductions to *social constructivism* is the work of Joan Solomon [29], who accepted the notion that knowledge is held by individuals but tried to incorporate into constructivist theories the role that social effects might have in modifying the ideas these individuals construct.

Peter Taylor, William Cobern, and Kenneth Gergen have taken different approaches to extending Solomon's concern with social influences on learning. Taylor's *critical constructivism* combines social constructivism with critical theory to develop a model of how the processes of teaching and learning are socially constructed [30, 31]. Taylor's model examines the barriers that must be overcome to create a constructivist classroom environment and suggests techniques for overcoming these barriers.

Cobern's *contextual constructivism* considers the effect of culture and world view as central forces in the development and organization of students' ideas [32]. Gergen's *social constructionism* focuses on the role of language in the development of knowledge [33]. Gergen is unique in rejecting the notion that knowledge resides within individuals. He takes a more extreme position, arguing that the processes by which language is used and meaning is constructed are social processes, which reside within groups or societies, and that these processes constitute knowledge.

Kelly's Theory of Personal Constructs

During a sabbatical leave at Curtin University, the first author was introduced to the work of George Kelly by his coauthor from that institution. His enthusiastic reaction to Kelly's work can be traced to two factors. First, Kelly provides an alternative form of personal constructivism that might be easier to understand (and accept) than the one described in his 1986 paper, which was based on Piaget's work. He was also struck by the similarity between the problems that confront the audience for whom Kelly wrote — the group of individuals who train clinical psychologists — and the problems faced by his colleagues in science education who work with pre-service and in-service teachers. We are not equating the students in our classes with the patients treated by clinical psychologists. We are, however, equating some of the skills that must be developed by the instructor who works with these students and the psychologist who must treat his or her patients. To be successful, both instructors and clinical psychologists must learn how to listen so that they can begin to understand what is happening in another person's mind.

George Kelly's two-volume treatise on *The Psychology of Personal Constructs: A Theory of Personality* [34] provided a model for the training of clinical psychologists. Perhaps the best way to introduce Kelly's theory is to quote his own words, with minor corrections inserted in brackets to transform a writing style appropriate for the 1950s into one that is acceptable today.

Kelly starts the first chapter in Volume I by recognizing the active role the individual has in the construction of knowledge. He argues that we each contemplate, in our own way, the stream of events upon which we are borne. To understand this metaphor, Kelly asks us to switch our perspective of human behavior. Instead of thinking about "man-the-biological organism," as the behaviorists who dominated psychology in his day recommended, he suggests that we think in terms of "man-the-scientist." When he uses this term, Kelly is speaking of the typical behavior exhibited by a typical individual, not the behavior of that special class of individuals "who have publically attained the stature of scientists."

Kelly describes what it means to think about individuals in terms of their scientist-like aspect by arguing that "It is customary to say that the scientist's ultimate aim is to predict and control." He continues building his model of "man-the-scientist" by noting that each of us shares the scientist's goal of trying to predict and control the course of daily events. In doing so, he argues, we develop theories, test hypotheses, and weigh experimental evidence about the sequence of events that mark our lives.

Kelly finesses one of the objections some have had to other versions of the constructivist theory by explicitly assuming that both the universe and people's thoughts are real. More importantly, Kelly recognizes that the correspondence between what people think exists and what really does exist is continually changing.

Kelly describes the relationship between the world in which we live and our thoughts by presuming that we look at our world through "transparent patterns" that we "fit over the realities of which the world is composed." He goes on to argue that the fit is not always very good, and yet without these patterns the world would appear so homogeneous we would not be able to make sense of it. Thus, "even a poor fit is more helpful ... than nothing at all."

Kelly proposes that these transparent patterns should be given the name *constructs*. He notes that "They are what enables [us] ... to chart a course of behavior, explicitly formulated or implicitly acted out, verbally expressed or utterly inarticulate, consistent with other courses of behavior or inconsistent with them, intellectually reasoned or vegetatively sensed."

Kelly argues that we each create our own ways of seeing the world; the world does not create them for us. Each of us builds our own constructs, tries them on for size, and eventually revises them. These constructs are sometimes organized into systems or groups of constructs. But the entire process of building, using, and revising constructs is driven by one primary goal: to help us predict, and therefore possibly control, future events. Kelly notes:

> ... we consider a construct to be a representation of the universe ... erected by a living creature and then tested against the reality of the universe. Since the universe is essentially a course of events, the testing of a construct is a testing against subsequent events. In other words, a construct is tested in terms of its predictive

efficiency. ... Just as constructs are used to forecast events, so they must also be used to assess the accuracy of the forecast, after the events have occurred.

An example of a set of constructs that are tested against subsequent events might include the common functional groups that represent the universe of organic compounds and their reactions. Recognizing the presence of an aldehyde, for example, provides a way to predict (and perhaps control) the reaction chemistry of a compound.

Kelly addresses an important issue for those struggling to understand why misconcepts are so remarkably resistant to instruction [35]. He argues that people sometimes hesitate to experiment because they dread the outcome; they fear that the results of the experiment will place them in an ambiguous position where they will no longer be able to predict and control future experiences. Kelly notes that evidence of this hesitance to experiment can be seen in an individual's reluctance to test his or her constructs. But a more practical problem for both psychotherapists dealing with their clients and teachers working with students results from Kelly's suggestion that the individual might also be reluctant to express his or her constructs, "lest [they] be trapped into testing them prematurely." Anyone with classroom experience should recognize the tendency of some students to do anything to avoid answering a question or expressing an opinion.

Kelly's theory provides a basis for discussions of what others call *alternative concepts*, *less-powerful concepts*, or *naive concepts* when he states: "Enough has already been said to make clear our position that there are various ways in which the world is construed." But he goes beyond this when he notes: "Some of them are undoubtedly better than others. They are better from our human point of view because they support more precise and more accurate predictions about more events." These predictions are not accurate in the classic scientific view — a better fit to reality. They are more accurate from the individual's view, they do a better job of predicting what happens to that individual.

Kelly provides a basis for understanding how an individual's conceptual knowledge changes with time: "We assume that all of our present interpretations of the universe are subject to revision or replacement. ... We take the stand that there are always some alternative constructions available to choose among in dealing with the world. No one needs to paint [oneself] into a corner; no one needs to be completely hemmed in by circumstances; no one needs to be the victim of [one's] biography."

More importantly, Kelly recognizes that some constructs are intrinsically more powerful than others: "We have now said enough about the testing of constructs to indicate that it is not a matter of indifference which of a set of alternative constructions one chooses to impose upon [one's] world. Constructs cannot be tossed about willy-nilly without a person's getting into difficulty. While there are always alternative constructions available, some of them are definitely poor implements. The yardstick to use is the ... predictive efficiency of each alternative construct and the over-all predictive efficiency of the system of which it would, if adopted, become a part."

Having laid the foundation for his theory of personal constructs, Kelly elaborates this theory in terms of a fundamental postulate and eleven corollaries, which we have reworded slightly to adapt his writing style to one appropriate for use today.

Fundamental Postulate: An Individual's Processes Are Psychologically Channelized by the Ways in Which He or She Anticipates Events

The fundamental assumption upon which Kelly's theory is built begins by noting that the emphasis of this theory is on the individual and the individual's psychological processes or behaviors. Kelly argues that these processes operate through a network of pathways, which is flexible and frequently modified, but which is also structured and both facilitates and restricts the individual's range of action. He compares these pathways to grooves cut out by the mechanism one adopts for realizing his or her objectives. The goal of this mechanism is to predict and control by anticipating future events.

Construction Corollary: Individuals Anticipate Events by Construing Their Replications

Kelly uses "construing" to describe a process by which an individual interprets events — and, in particular, their repetition — in terms of characteristic elements that emphasize both similarities and contrasts. He notes: "Once events have been given their beginnings and ending, and their similarities and contrasts construed, it becomes feasible to try to predict them, just as one predicts that a tomorrow will follow today. What is predicted is not that tomorrow will be a duplicate of today but that there are replicative aspects of tomorrow's event which may be safely predicted."

Individuality Corollary: Individuals Differ from Each Other in Their Construction of Events

Because the fundamental postulate emphasizes the ways in which a person anticipates events, it provides the groundwork for individual differences. Or, as Kelly states it: "People can be seen as differing from each other, not only because there may have been differences in the events which they have sought to anticipate, but also because there are different approaches to the anticipation of the same events. ... No two people can play precisely the same role in the same event, no matter how closely they are associated."

This doesn't mean that these individuals can't share experiences. Although there are individual differences in the construction of events, people can find common ground by construing the experiences of their neighbors. Kelly notes, however, that finding a common ground is not inevitable, particularly when there are cultural differences among the individuals seeking common ground with their neighbors. As he states it: "... individuals can be found living out their existence next door to each other but in altogether different subjective worlds." The absence of a common ground is a particularly important barrier to communication between instructors and their students, between husbands and wives, between parents and children, between individuals of different ethnic backgrounds, and so on.

Organization Corollary: Individuals Evolve for Their Own Convenience in Anticipating Events a Construction System Embracing Ordinal Relationships Between Constructs

Kelly uses the term *construction system* to describe what happens when a series of constructs with similar, but not identical, elements are grouped to minimize incompatibilities and inconsistencies between their elements to avoid making contradictory predictions.

Dichotomy Corollary: An Individual's Construction System Is Composed of a Fine Number of Dichotomous Constructs

Chemists, who differentiate between acids and bases, metals and nonmetals, oxidation and reduction reactions, polar and nonpolar compounds, ionic and covalent compounds, protic and aprotic solvents, and so on, should be particularly sensitive to the role that dichotomous constructs can play in the development of conceptual knowledge.

Choice Corollary: Individuals Chose That Alternative in a Dichotomized Construct Through Which the Greater Possibility for Extension of the Construct System Can Be Anticipated

This corollary was designed to explain why therapists often have difficulty understanding why their clients continue to make the "wrong" choices, in spite of insights provided by the therapist that would appear to make it clear how the client should behave. But it seems to be equally valid as a basis for helping us understand the "wrong" choices students make, in spite of clear instruction from us. The source of confusion is the same for the therapist and the teacher — the decisions in question are made within the context of a system of personal constructs the client or student has erected.

Range Corollary: A Construct Is Convenient for the Anticipation of a Finite Range of Events Only

Kelly defines a "range of convenience" as that portion of the real world over which a given system or theory provides useful coverage. He uses the construct of tall vs. short as an example of a construct with a limited range of convenience: "One may construe tall houses versus short houses, tall people versus short people, tall trees versus short trees. But one does not find it convenient to construe tall weather versus short weather, tall light versus short light, or tall fear versus short fear." He also notes that therapists are often surprised to learn how narrowly individuals apply some of their constructs, particularly those that have only recently been established. The same, of course, can be said for the constructs students build in their chemistry courses.

Experience Corollary: An Individual’s Construction System Changes as the Replications of Events Are Successively Construed

This corollary rings a responsive chord in light of what we know about other forms of the constructivist theory. Kelly argues: “The succession of events in the course of time continually subjects a person's construction system to a validation process. The constructions one places upon events are working hypotheses, which are about to be put to the test of experience. As one's anticipations or hypotheses are successively revised in the light of the unfolding sequence of events, the construction system undergoes a progressive evolution.” Kelly notes that experience isn’t constituted merely by the succession of events to which one is subjected, but by the successive construing of these events. He notes that an individual can be a witness to a “tremendous parade of episodes,” and yet, by failing to make something of them or waiting until they have all occurred before attempting to reconstrue them, gain little in the way of experience from “having been around when they happened.”

Modulation Corollary: Variations in an Individual's Construction System are Limited by the Permeability of the Constructs Within Whose Range of Convenience the Variants Lie

The experience corollary states that the individual’s construction system changes as the individual successively construes the replications of events. But these changes can only occur within the limits of the permeability of the constructs that form the system. According to Kelly, permeable constructs are not necessarily loose, inconsistent, or tenuous. They are permeable in the sense that they have the capacity to embrace new elements.

Fragmentation Corollary: An Individual May Successively Employ a Variety of Construction Systems Which Are Inferentially Incompatible with Each Other

The fragmentation corollary explains a phenomenon that is all too common when we observe the long-term development of an individual: new constructs are not necessarily direct descendants of one's old constructs. Furthermore, predictions based on new variants of a construct are not always compatible with those that would be made on older variants anymore than predictions from the perspective of the Lewis acid-base theory are necessarily compatible with those obtained from the Brønsted or Arrhenius theories.

Commonality Corollary: To the Extent That One Individual Employs a Construction of Experience Which Is Similar to That Employed by Another, That Individual's Psychological Processes Are Similar to Those of the Other Individual

The commonality corollary provides a counterbalance to the individuality corollary, which assumes that people involved in the same events can experience them differently because they construe them differently. The commonality corollary suggests that it would be absurd to assume that two individuals had to live through identical events to either act or think alike.

Sociality Corollary: To the Extent That One Individual Construes the Construction Processes of Another, That Individual May Play a Role in a Social Process Involving the Other Person.

Anyone who has been married, or even survived a long-term relationship, should accept Kelly's notion that one can only play a constructive role in a relationship if, at least in some measure, one can accept the other person's way of seeing things. Anyone with classroom experience should appreciate the legitimacy of Kelly's argument that: "If we can predict accurately what others will do, we can adjust ourselves to their behavior. If others know how to tell what we will do, they can adjust themselves to our behavior ... Understanding does not have to be a one-way proposition; it can be mutual." Understanding does not mean that two individuals have the same construction system, but rather that they have made some progress toward understanding each other so that they can play roles in relation to each other.

The Scientist in the Crib

The metaphor of "man-the-scientist" and many of the corollaries proposed by Kelly in 1955 have been reinforced by recent work on learning by infants. In a book entitled *The Scientist in the Crib*, [36] the authors compare infant development with the way scientists formulate and test theories. They note that infants start out with a theory of the world that is not quite correct. As they operate with it, they come up with anomalies or puzzling findings. When that happens, "they furrow their brows, look at the problem, and then hide the rattle underneath the cloth, take it out again, hide it again. They're actually performing experiments, trying to understand what's going on."

Conclusion

Even critics of the constructivist theory who worry about whether it has become "something akin to a secular religion" note "that there is a very broad and loose sense in which all of us these days are constructivists ..." [37] Readers interested in going beyond the individual articles on the evolution of constructivist theories cited above might consult the books edited by Tobin [38] and Steffe and Gale [39], which include chapters on the nature of the constructivist theories, on the construction of knowledge and group learning, on classrooms and labs as sites for construction of knowledge, and on how various individuals have implemented the constructivist theory in their classrooms.

Our goal in writing this paper was to provide a glimpse of a few of the different forms (or faces) of the constructivist theories and their implications for the teaching of chemistry. We have placed particular emphasis on Kelly's theory because, although it emphasizes the role of the individual in the construction of knowledge, it provides a basis for thinking about the kinds of interactions between people that can facilitate this construction. It therefore satisfies our original goal of providing a theoretical framework on which we can base decisions that shape the way we teach chemistry.

Notes:

[1]A new edition of Perry's book was published by Jossey-Bass Publishers in 1999.

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