Chapter 15 The Physical Science Framework

§ 1. The Definitional Issue of Science

Language art and mathematics are propaedeutic to almost every aspect of adult life in a modern Society. Their place in a public school curriculum is unchallengeable for that reason. But can the same be said for science? No one actually seems to challenge the notion that something called "science" ought to be a mandatory component of a public school curriculum. But what is this something and why should it be deemed proper that *every* pupil should study it when the great majority of citizens do not choose to become practicing scientists? What is it that every pupil should be expected to learn about science and how is this expectation justifiable under the social contract of a Republic?

Let us start with the object of this topic and ask, "What is science?" Webster's Dictionary lists five contextual usages of the term:

> **science**, *n*. [Fr. *science*, from L. *scientia*, knowledge, from *sciens* (*-entis*), ppr. of *scire*, to know.]
>
> 1. originally, state or fact of knowing; knowledge, often as opposed to *intuition*, *belief*, etc.
> 2. systematized knowledge derived from observation, study, and experimentation carried on in order to determine the nature or principles of what is being studied.
> 3. A branch of knowledge or study, especially one concerned with establishing and systematizing facts, principles, and methods, as by experiments and hypotheses; as, the *science* of music.
> 4. (a) the systematized knowledge of nature and the physical world; (b) any branch of this.
> 5. skill, technique, or ability based on training, discipline, and experience. [Webster (1962)]

There are three broad contexts contained in this list of usages. The first can be summed up by saying science is systematic knowledge of some topic or object or "branch" of knowledge. This context regards science as a metaphorical tree of systematized knowledge. The second broad context regards science as a practice of inquiry (study). The third regards science as the skills and techniques for carrying out such a practice. Curiously missing from Webster's usages is the context of applying or using knowledge gained by means of such a practice. In a loose and imprecise way, this missing context might be called "engineering," although such a labeling arguably over-generalizes the idea of 'engineering' as this term is used by colleges of engineering to describe what it is that they teach. To illustrate the latter, here are a few representative self-descriptions taken from the websites of one private and two land grant universities:

> **Stanford University:** "We think of engineers as people who take discoveries from the sciences and use them to solve problems that change the world."
>
> **Iowa State University:** "What does an engineer do? Creatively solve problems. Bring science to everyday use. Apply technology to make our world a better place."
>
> **The University of Idaho:** "Members of the engineering profession use their knowledge of mathematics and the sciences to create useful and economic devices, structures, and systems for the benefit of the earth and its inhabitants."

The National Research Council (NRC) recently published a "Next Generation Science Standards" (NGSS) document [National Research Council (2012)] in which the science framework merges the traditional usages of "science" and "engineering" into the same framework. Because the

NGSS framework is being used as the model framework by many of the states in developing their Common Core State Standards Initiative science frameworks, all four of the above contexts have some pertinence for the institution of public education at the K-12 public school level.

With Lavoisier's *dictum* in mind (chapter 14), it is quite apparent that this *potpourri* of usages will not do for answering the question at hand because it leaves matters set too imprecisely. It is as if someone were to say, "I specialize in bird watching, cooking, and nuclear physics." So, what object shall be meant by the word "science"? The modern distinction drawn between philosophy and science was first set down by Kant. He tells us,

> Every doctrine, when it is a system – that is, a whole of knowledge ordered according to principles – is called a science; and because such principles may be either fundamental principles of *empirical* or *rational* connection of knowledge into a whole, then natural science . . . would have to be divided into *historical* or *rational* natural science were it not that the word *nature* . . . makes necessary a knowledge through reason of the context of natural things insofar as this is to deserve the name of a science. [Kant (1786), 4: 467-468]

From this comes Kant's Critical *Realerklärung*, i.e., ***science*** is ***any doctrine constituting a system in accordance with the principle of a disciplined whole of knowledge***.

A ***doctrine*** is *that theoretical knowledge in which one comes across the grounds for how an object-matter can be trained up or the rules hit upon according to which a good product can be produced* [Kant (*c*. 1770), 24: 228]. A science, therefore, is not the body of knowledge arranged under its topical principle *per se*; that is only the object-matter or 'topical matter' of that science. The idea of 'science' contains an idea of how the topical knowledge is ordered and arranged so that this knowledge can be both *taught and used*. If you have discovered something but you cannot teach it to others or put your knowledge of it to practical use then that which you know about your discovery is not knowledge of a science.

A consequence of Kant's *Realerklärung* of science is that, viewed in the context given by the divers explanations offered by the colleges of engineering quoted above, *engineering is a science*. One of the useful contributions contained in the NGSS framework is that the framework recognizes engineering instruction as a component of science instruction. The American tradition of making a separation between "colleges of science" and "colleges of engineering" is a result of the influence the German model of higher education had on 19th century American educators. German higher education distinguishes between a *Fachschule* (trade or technical school) and a *Hochschule* (college) and usually assigns 'engineering' to the former and 'science' to the latter. It is an artificial distinction that runs contrary to the understanding of science set out by Bacon in his call for the developments and advancements that started our modern scientific era:

> There is another powerful and great cause of the little advancement of the sciences, which is this: it is impossible to advance properly in the course when the goal is not properly fixed. But the real and legitimate goal of the sciences is the endowment of human life with new inventions and riches. [Bacon (1620), pg. 58]

Another noteworthy aspect of the *Realerklärung* of science is that its real explanation has not one thing to do with schools, including universities. You do not have to attend a college or earn a degree in some officially-recognized disciplinary major in order to be a scientist. The litmus test of whether or not a person is a scientist is set out by the questions: (*i*) do you have and follow a doctrine of a disciplined whole of systematic knowledge about some object-matter?; and (*ii*) can you teach this doctrine to other people? A carpenter is a scientist *if* his knowledge of carpentry is organized and disciplined according to principles of which he is cognizant *and* if he can teach carpentry *and its principles* to others. If not then he is only a craftsman. Aristotle wrote,

> It would seem that for practical purposes experience is in no way inferior to art; indeed, we see men of experience succeeding more than those who have theory without experience. The reason for this is that experience is knowledge of particulars, but art of universals; and all actions and efforts produced are all concerned with the particular. . . . So if a man has theory without experience, but does not know the particular contained in it, he will often fail in his treatment for it is the particular that must be treated. Nevertheless we consider that knowledge and proficiency belong to art rather than experience, and we assume that artists are wiser than men of mere experience . . . and this is because the former know the cause whereas the latter do not. For the experienced know the fact but not the wherefore; but the artists know the wherefore and the cause. [Aristotle (*c*. 335-322 BC), vol. I, Bk. I, pp. 5-7, 981^{a}10-981^{b}1]

The habit and tradition of regarding some of the technical arts (and every science is a technical art) as superior to the others is nothing but empty hubris. Some technical arts bring their practitioners a more lucrative revenue income than others but this is a mere matter of economics and is not due to some inherent value subsisting in the art itself. If you are starving who do you value more, a farmer or a physicist? If your car has broken down who do you value more, a master mechanic or a mathematician? If you want to build a house who do you value more, a master carpenter or a civil engineer? Your answer is known by who you hire to do the work.

This, then, answers the first question: What is science? Having the real explanation secured leads directly to an understanding that science *instruction* is not the same thing as the science about which a learner is receiving instruction. Furthermore, it is immediately plain that for any school to attempt to teach the learners skills in every possible science is a laughably impractical goal for public education for many different reasons. Furthermore, an attempt to do such a thing is not congruent with the functions of public instructional education (figure 1). What, then, must science instruction in a public school Institute accomplish?

§ 2. The Relationship of Science Instruction to Public Education Function

The educational functions that justify *public* education were derived in *Education and Society* (volume I of *The Idea of Public Education*) and are summarized in figure 1. A science curriculum

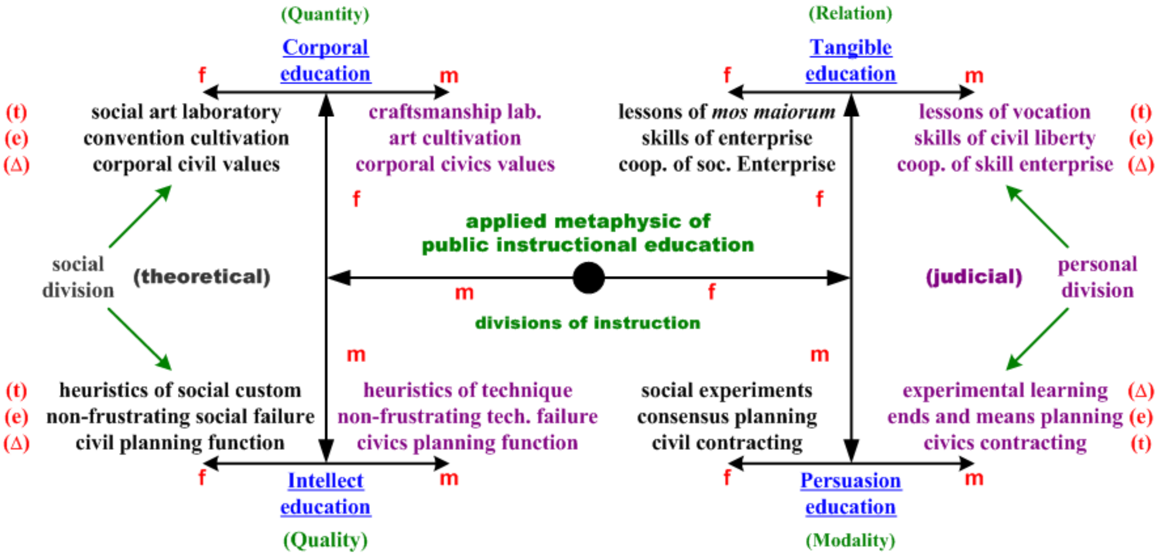

Figure 1: The functions of public instructional education.

is congruent with the justification of public instructional education if and only if it serves some subset of these functions and is congruent with the general *Realerklärung* of science that has just been discussed. Chapter 10 overviewed the twenty-four functions of public instructional education and discussed aspects of curriculum and course design to be developed from them.

Examination and analysis of the real explanation of science, when this analysis is confined to topics of *physical-natural* science, leads to the conclusion that the functions served by science instruction all fall within the personal dimension of the learner and pertain to the power of his person. It further shows there are nine functions among the twenty-four to which science instruction is required by the justification of *public* education to be made directly pertinent. These are:

1. the craftsmanship laboratory function (corporal education);
2. the art cultivation function (corporal education);
3. the heuristics of technique function (intellect education);
4. the non-frustrating technical failure function (intellect education);
5. the civics planning function (intellect education);
6. the lessons of vocation function (tangible education);
7. the skills of civil liberty function (tangible education);
8. the heuristics of experimental learning function (persuasion education); and
9. the ends and means planning function (persuasion education).

None of these functions are specific to any particular occupation. Given typical conceptions and misconceptions about science held in the U.S., this merits a brief commentary. The general idea of science is open-ended inasmuch as it is specific to no disciplinary field. *Any* technical art can be made into a science. Indeed, presently recognized sciences *all* came into being because a sufficient number of people decided to devote enough in-depth study to their particular topical areas such that eventually specialized knowledge in these areas was advanced to the point where knowledge of the topic met the conditions that are called out in Kant's real explanation of science. A great many of today's sciences originated in philosophy and emerged as recognized fields of study when their scopes of interests became too narrow to suit the normal general designation of what is said to constitute 'philosophy.' Physics and psychology are both examples of this. Others of today's officially recognized sciences emerged initially as subdisciplines of older, already established and recognized sciences or from some specialized integration of subtopics within two or more already established and recognized sciences. All the divers branches of engineering originated in this way from combinations of subtopical interests in older sciences and special topical knowledge applications in divers crafts and economic enterprises.

There is a popular misconception among laypeople that the sciences are in some way a set of permanent disciplines whose collective scope has grown to cover a putative universe of 'scientific knowledge.' This is not true. All sciences are invented, whether because of the personal curiosity of their founders or in answer to some need that comes to be recognized by a Society. The roll call of the sciences is not static. As examples: The science of physics is largely credited to Isaac Newton *circa* 1726; the *social-natural* science of economics is credited to Adam Smith in 1776; the science of information theory was invented by Claude Shannon in 1949; the science of modern system theory[1] originated during the 1950s and early 1960s largely due to the works of Richard E. Bellman, Rudolf E. Kalman, and Theodore R. Bashkow; computational neuroscience is currently emerging as a new science. A Society's continued Progress and development is as dependent on on-going inventions of new sciences as it is on guarding against the decline and

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[1] The science of modern system theory is not to be confused with general usages of the term 'systems theory' used to characterize various activities (e.g., "General Systems Theory") that have not yet risen to a level where they can be legitimately called sciences. The Wikipedia entry for "systems theory" describes some examples of this class of not-yet-sciences.

decay of existing ones. This treatise, therefore, approaches and treats science *education* from this *general* perspective. *Public* science education must not be viewed in the narrow focus of training for existing occupations. It must rather be seen as an education that cultivates learner *Personfähigkeit* in such a way as to cultivate Progress in scientific knowledge for the benefit of the Society which provides that public education. Curtis Wilson wrote,

> The role of modern science in liberal education is the subject of widespread and intensive discussion. What should that role be?
>
> Decade by decade, the pace of research in the physical and biophysical sciences is accelerating; and decade by decade the picture of the world which results from such research becomes stranger, more esoteric, more complicated. There is even a certain justification in saying that the picture becomes less and less a picture, less and less an imaginable model of what is, and more a set of complicated mathematical formulas connected with a set of complicated procedures for getting results. . . .
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> Lack of immediate intelligibility in science itself and the urgency of continued and accelerated scientific development – these are probably the principal facts which confront the non-scientist when he thinks about science. Both facts present themselves as external, hard necessities; neither fact, the non-scientist may be inclined to add, seems to touch the nerve of our lives. . . .
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> One requirement of liberal education in science should thus be clear. Liberal learning in the sciences is primarily concerned neither with the factual data uncovered by science nor with the hypotheses and theories which form its body; it is rather concerned with the artifices of the human mind and hand which help us transcend the factual by reducing it to universal principles. Information is necessary but not sufficient; the mind must be encouraged and guided to think through to the roots of scientific ideas. [Wilson (1960), pp. v-vii]

Physical-natural science differs from social-natural science in terms of its objects and its basic principles. The objects of physical-natural science are all objects of sensible real experience and, furthermore, they are all what Critical metaphysics calls "dead matter objects" because what can actually be studied by the methods of physical-natural science are understood in such a way that, as objects, nothing in their *scientific* understanding includes the Critical idea of ***life*** in the *Realerklärung* of that term[2].

This includes *all* objects studied in the discipline of biology despite the label "life science" that is attached to this discipline. To many readers it may seem odd indeed that biology excludes the *general* idea of life from its doctrine[3]. This, however, was necessary in order for biology to be freed from useless and hindering limitations the practices of biology, physiology, and medical science suffered under vitalism. It was Claude Bernard who effected this revolution in biology:

> Now the absence of the scientific habit of mind is a serious hindrance, because it favors belief in occult forces, rejects determinism in vital phenomena, and leads to the notion that the phenomena of living beings are governed by mysterious vital forces which are continually invoked. When an obscure or inexplicable phenomenon presents itself, instead of saying "I do not know," as every scientific man should do, physicians are in the habit of saying, "This is life"; apparently without the least idea that they are explaining darkness by still greater darkness. We must therefore get used to the idea that science implies merely

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[2] refer to the technical glossary for the *Realerklärung* of life.

[3] more or less recently (in the latter half of the 20th century) a technical term called "life" was *defined* for the biological sciences in such a way that the term could be used with real objective validity. However, it is a specialized and empirico-mathematical term that must properly be called "biological life." I provide the definition of this term in the follow-on text in this section. Biological life is a principal quantity in biology.

> determinable conditions of phenomena; and we must always seek to exclude life entirely from our explanations of physiological phenomena as a whole. Life is nothing but a word that means ignorance, and when we characterize a phenomenon as vital, it amounts to saying that we do not know its immediate cause or its conditions. Science should always explain obscurity and complexity by clearer and simpler ideas. Now since nothing is more obscure, life can never explain anything. [Bernard (1865), pg. 201]

When biological knowledge finally advanced to the point where biologists could identify two physically observable conditions that were present in everything that all biologists agreed were to be called "living things," it became possible to *mathematically* define something properly called ***biological life***. Biologists in practice merely use the term "life," but they mean something very different by this term than laypeople do. This still-recent technical definition of biological life is

> [biological] life: Complex physico-chemical systems whose two main peculiarities are (1) storage and replication of molecular information in the form of nucleic acid, and (2) the presence of . . . enzyme catalysts. [Thain & Hickman (2004)]

Even this definition has issues in biology. Enzyme catalysts are not present in viruses. There is a certain amount of controversy among biologists over the question of whether or not to regard a virus as a "living thing." Most biologists, regardless of their ontological preferences, settle for using the terms "active" or "inactive" to describe viruses. Viruses are, however, definitely objects of biology. What I call your attention to here is that this definition merely defines *a way to classify objects into categories according to which a thing is regarded as either an-object-of-biology, not-an-object-of-biology*, or, in the case of viruses, an *object-of-interest-to-biology*. There is no further significance to this definition than that, and this significance is entirely epistemological. In great contrast, human beings *are* understood in such a way that the Critical *Realerklärung* of life *does* apply to us, and so a human being is a "live matter" object, not a dead matter one. All the objects *studied by* biology and its sub-branches are dead matter objects.

One of the most fundamental principles distinguishing the sciences of dead matter objects (physical-natural science) from the sciences of live matter ones (social-natural science) is this: In the physical-natural sciences, all causative explanations must be stated in terms of *physical* causality & dependency and can *never* posit causative explanations that employ *psychological* causality & dependency (teleological causality & dependency). Physical-natural sciences deal only with efficient causes. In contrast, causative explanation in social-natural sciences *can only* be understood in terms of *goal-directed* causality & dependency. This distinction makes physical-natural sciences *different in kind* from social-natural sciences. That difference makes the methods that can validly be employed different for the one than for the other[4].

I take up the case of social-natural science in chapter 16. For the remainder of this chapter the

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[4] This difference, by the way, also means that physical-natural sciences, including biology, *must* exclude "creationism" and its companion topics because these base their root explanations on teleological causality & dependency – specifically, teleological causality of the will of God. The domain of natural science is nature and natural phenomena; that of religion and theology is *super*nature. Natural science cannot speak *at all* about supernature with any objective validity whatsoever; religion and theology cannot speak *at all* about nature with any objective validity whatsoever. The respective objects are *totally* orthogonal to each other. Science can ***never*** claim to prove or disprove *anything* about supernature. Theology *must* accept the *Dasein* of God as its first premise and construct a doctrine of subjective *faith* in religious holding-to-be-true (because the idea of God lies beyond the horizon of possible experience). This means theology is not and can never be constituted as a science. It is when *and only when* this demarcation is trespassed that science and theology are *brought* into conflict with each other. Religion without theology is superstition according to the definition of the word 'superstition' [Webster (1962), usage 1]. Statements about supernature are religious statements and any scientist making one is not speaking *as a scientist*.

discussion is confined to education for physical-natural sciences.

§ 2.1 The Corporal Education Functions

The specifying concept of corporal education is scheme-building. The corporal education part of the curriculum aims to cultivate learner sensorimotor skills and practical maxims in his manifold of practical rules, including practical maxims of thinking by means of which Reason directs the employment of his process of determining judgment. Construction of practical schemes precedes cognizance of them [Piaget (1974)], and in the context of physical-natural science education this characteristic of mental development forewarns that the earliest meaningful experiences of science education must involve active manual explorations and observations by manipulations.

The craftsmanship laboratory function is a curriculum of physical exercises that are designed to teach the learner how to employ the physical capacities of his body in building sensorimotor schemes by which he can master any craft involving divers kinds of dead-matter objects he can be reasonably anticipated to encounter in life. In the case of physical-natural science instruction, this function requires learners to gain immediate experience with natural phenomena by conducting actual manipulations and doing teacher-designed experiments-to-see-what-happens exercises.

One thing I cannot overemphasize is this: ***computer simulations are not experiments***. A computer program is a product of pure mathematics; the computer will carry out precisely and *only* the steps it has been programmed to do, and *nothing* in a computer program is a *physical* phenomenon. A computer simulation is not a physical experience in which the learner comes into contact with natural phenomena. All computer simulations represent only idealized objects of mathematics. Natural phenomena are never perfectly replicated by a computer simulation because all computer simulations are only mathematical *models*.

This is something most learners (and even some teachers and occasionally some scientists – who ought to know better) often do not grasp. A theory is a *model* of phenomena, not the actual phenomena. A theory is mathematically apodictic; an experiment never is. This is something that Nobel laureate Richard Feynman tried to teach his physics students:

> If you insist upon a precise definition of force, you will never get it! First, because Newton's Law is not exact, and second, because in order to understand physical law you must understand that they are all some kind of approximation.
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> Any simple idea is approximate; as an illustration, consider an object, . . . what *is* an object? Philosophers are always saying, "Well, just take a chair for example." The moment they say that, you know that they do not know what they are talking about anymore. What *is* a chair? Well, a chair is a certain thing over there . . . certain?, how certain? The atoms are evaporating from it from time to time – not many atoms, but a few – dirt falls on it and gets dissolved in the paint; so to define a chair precisely, to say exactly which atoms are chair, and which are air, or which atoms are dirt, or which atoms are paint that belongs to the chair is impossible. So the mass of the chair can be defined only approximately. In the same way, to define the mass of a single object is impossible, because there are not any single, left-alone objects in the world – every object is a mixture of a lot of things, so we can deal with it only as a series of approximations and idealizations.
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> The trick is the idealizations. To an excellent approximation of perhaps one part in 10^{10}, the number of atoms in the chair does not change in a minute, and if we are not too precise we may idealize the chair as a definite thing; in the same way we shall learn about the characteristics of force, in an ideal fashion, if we are not too precise. One may be dissatisfied with the approximate view of nature that physics tries to obtain . . . and we may prefer a mathematical definition; but mathematical definitions can never work out in the real world. [Feynman *et al*. (1963), vol. I, pg. 12-2]

It has been my observation that nearly every learner naively believes whatever happens to come out of the computer. Even some experienced professionals sometimes do. Whenever they do, they are in serious jeopardy of learning something that isn't true. There is an old aphorism about computers often heard when I was young but not often heard anymore: *Garbage in, garbage out*.

By the time a preoperational stage child enters school, he is no stranger to active experimentation unless something in his early upbringing has actively discouraged experimentation behavior. Experimentation behavior is demonstrated by infants as early as about age 11-12 months [Piaget (1952), pp. 263-330]. In accomplishing the craftsmanship laboratory function for the case of very young children, it is more a matter of providing designed situations for unleashing experimenting than it is a matter of teaching it. All experimentation consists basically of three principal things: (1) an observation of a phenomenon to be understood; (2) observation of a second phenomenon to be compared to the first; and (3) a judgment comparing them. The *eventual* goal of instruction, which is accomplished only *gradually* by the learner, was described by Bernard, who tells us,

> In all experimental knowledge, indeed, there are three phases: an observation is made, a comparison established and a judgment rendered. By the experimental method, we simply make a judgment on the facts around us, by help of a criterion which is itself just another fact so arranged as to control the judgment and to afford experience. . . .
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> Two things must, therefore, be considered in the experimental method: (1) the art of getting accurate facts by means of rigorous investigation; (2) the art of working them up by means of experimental reasoning, so as to deduce knowledge of the law of phenomena. We said that experimental reasoning always and necessarily deals with two facts at a time: observations, used as a starting point; experiment, used as conclusion or control. In reasoning, however, we can distinguish between actual observation and experiment only, as it were, by logical abstraction and because of the position in which they stand.
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> But outside of experimental reasoning, observation and experiment no longer exist in this abstract sense; there are only concrete facts in each, to be got by precise and rigorous methods of investigation. We shall see, further on, that the investigator himself must be analyzed into observer and experimenter; not according to whether he is active or passive in producing phenomena, but according to whether he acts on them or not to make himself their master. [Bernard (1865), pp. 12-13]

A young learner is not capable of accomplishing all these pieces of experimental reasoning all at once. There are skills he must first develop: skills of observation; skills of manipulation; skills of making comparisons. My point here is that a *teacher's* expectations for how fast a learner can accomplish and integrate these pieces must not be set impatiently. Relatively little can be accomplished by a learner in any *one* lesson. Instruction *téchne* must from the beginning be designed to accomplish an overall learning objective as a culmination of a sequence of learning experiences – which in the case of young children might extend over an interval of a few *years*. It is by *integration* of *accumulating experiences* that skill in science is developed, not by particular object lessons. This is contrary to typical assessment and grading methods, both old and new, that have been in habitual practice in schools for many years. The traditional assessment and grading methods *are too impatient*. They attempt to chop up science instruction into bite-sized pieces; but to chop up instruction in this way *is to destroy its system* and, *ipso facto*, destroy the science.

There is a subtlety in Bernard's thesis. It is this: *Experiment subsists in bringing facts together*, not in the tools and trappings by which these facts are brought together. For the majority of sciences, how the practicing of science is carried out in a chemistry laboratory or a physics laboratory *is irrelevant and impertinent* to other special sciences. Consider geology as an example. There are relatively few geology experiments that can be carried out in a laboratory. But it is quite wrong to conclude from this that geology is a non-*experimental* science. It is merely a non-*laboratory* science. Note Bernard's phrase, "experimental reasoning," which he uses again and again. What most of us are taught to regard as "an experiment" – a thing that involves Bunsen burners or spring scales or the like – *is not the experiment*; *it is only a manipulation that uncovers a fact*. The experiment subsists in the experimental reasoning that is exercised over facts. Children, of course, will not be ready to carry out the sorts of judgmentation and reasoning we typically associate with a scientist until their late middle school and high school years. That is why only lesson *sequences* cultivate science skills; the capacity for experimental reasoning is an end objective for science education. Particular science topics merely provide *materia ex qua* for the learner's education; they are not the *materia in qua* of science skill.

Having said this, I most urgently feel it is necessary to add something. It is this. The fact that the specific topical matter of science does not particularly matter, insofar as the learner's development of scientific *skill* is concerned, *does not mean the teacher does not have to know science in detail*. The fecundity of science is owed to knowledge of details, to particulars, integrated to make a *system* of knowledge. A teacher does not have to be a deep specialist in a branch of science, but a teacher does have to know enough science in detail – preferably from more than one science – in order to know how to cultivate the learner's knowledge of detail. Because science instruction is to begin in primary school, this means primary school teachers must be knowledgeable enough about science to teach it there. A person who is not knowledgeable in the rudiments of actual scientific practice and theory cannot teach science. Indeed, if *education doctrine* is to be made into a scientific doctrine, *every* teacher must learn how to be a scientist. Every practitioner of a science is a scientist. Every effective teacher is an applied psychologist (among other abilities).

The craftsmanship laboratory function is aimed at the practical skill development propaedeutic to the development of scientific reasoning skills. But the learner must also be able to express by action the manipulations required to uncover facts and bring them together. This is where the second corporal education function enters in. The art cultivation function is comprised of designed corporal activities aimed to develop the learner's abilities to accomplish things in terms of schemes of how-it-can-be-done. Picture, for example, the progressive exhibitions seen when a little child gradually learns to pour milk in a glass. The early efforts are clumsy and the table or floor is as likely to receive the milk as the glass is. But in time the child comes to be able to put all the milk in the glass. This is how-to skill development. It is the same with science; only the length of time required to accomplish the skill development differs. Indeed, early failures in the learner's experimental manipulations hone and promote the objective understandings that are the aims of the intellect education functions discussed in the next section. Piaget noted cognizance of actions is developed out of comparison of goals with actual results. Art cultivation in corporal education is aimed at cultivating and developing these types of skills of cognizance.

One might be tempted to assume the corporal education functions pertain only to young pupils but such an assumption is false. Every learner advancement in object knowledge is necessarily preceded by advancements in practical knowledge – which always essentially depends on the functions I have been discussing. James Clerk Maxwell, the physicist who developed the theory of electromagnetism upon which electrical engineering is based, wrote,

> I have confined myself almost entirely to the mathematical treatment [of electricity and magnetism], but I would recommend the student, after he has learned, experimentally if possible, what are the phenomena to be observed, to read carefully Faraday's *Experimental Researches in Electricity*. He will find there a strictly contemporary historical account of some of the greatest electrical discoveries and investigations, carried on in an order and succession which could hardly have been improved if the results had been known from the first, and expressed in the language of a man who devoted much of his attention to the methods of accurately describing scientific operations and their result. [Maxwell (1873), vol. I, pg. xi]

Maxwell quite likely would not approve of the modern way in which electromagnetism is taught in colleges today. The modern treatment begins with the mathematics and theory and only afterwards tries to "demonstrate the theory" in the laboratory – if, indeed, the school bothers with the laboratory at all. This sequence is contrary to effective learning of the topic. The sequence *from* practical-and-actual *to* mathematical-and-theoretical *cannot be commuted* and still achieve the same outcome no matter how gifted a teacher's skills of presentation may be. It is quite wrong to think experiment demonstrates theory; rather, theory explains phenomena already observed[5]. I am embarrassed for my profession to have to tell you that most electrical engineering graduates understand very little about electricity and magnetism because of the backward sequence by which it is taught. It is essential to the development of skill in scientific reasoning for a learner to have *first* contacted actual phenomena *before* mathematics and theory can be meaningful to him.

In closing this section, I feel it is necessary to point out that traditional funding of public education, the purse strings of which have long been controlled by state legislatures and boards of education, have provided wholly inadequate fiscal support for material resources needed to support the corporal education functions just discussed. This is a contributing factor to the overall breakdown of the American institution of public instructional education documented in volume II [Wells (2013)]. The plain historical fact of the matter is this: Those who have held the decision making power over how funds for public education are to be used have always operated under an instituted Taylorism; their directives have been top-down based on the decision-makers' own presuppositions and prejudices about how to educate learners; and the great majority of the Taylorite decision makers have been incompetent to make these *technical* decisions. The situation is one of the several foundational reasons the organizational reforms discussed in Part I of this treatise are necessary for successful public education reform.

§ 2.2 The Intellect Education Functions

In discussing the functions of intellect, tangible, and persuasion education, I begin by stating that there are fecund connections between the *functions* and *some* of the framework ideas contained in the 2012 NGSS document [National Research Council (2012), appendices F, I] *provided* the framework ideas are interpreted epistemologically. The relationships between instructional functions and practices called out in the NGSS are not one-to-one. Curriculum designs *by teachers* must be developed with full awareness that a *synthesis* of the functions and those NGSS framework ideas which are fecund and not-incorrect is still required in order to produce an effective *actual* curriculum. There are also some important misconceptions built into the NGSS framework document. These problems are traceable to fundamental misunderstandings of what 'science' is and what 'engineering' is. I discuss problems with and contributions made by the NGSS framework in the course of discussing the instructional functions.

The specifying concept of intellect education is *intelligence building* (chapter 10). Intelligence building means the constructing of mental schemes for how to effectively adapt knowledge to uses. There are three functions of intellect education pertaining to the framework of physical-natural science: the heuristics of technique function (provision in the curriculum of exercises through which the learner practices developing his ability to construct heuristic procedures applied to dead-matter objects); the non-frustrating technical failure function (inclusion in the curriculum of non-frustrating failure experiences involving dead-matter objects); and the civics planning function (inclusion in the curriculum of exercises that stimulate the learner's development of procedural schemata applied to technical objects).

2.2.1 One rather obvious question pops up almost at once in regard to intelligence building: If

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[5] If a theory is fecund, it also makes predictions and suggests follow-on experiments to confirm prediction. But this aspect pertains to the practice of science, not its teaching.

the functions of intellect education all involve cultivating a learner's ability to adapt what he knows in order to use it for specific purposes, *what function of instructional education provides the learner with the root knowledge he is to adapt to serve his purposes?* You might have wondered about this back in chapter 10 when the functions were described and summarized. The answer might surprise you. *It is the* ***non-frustrating technical failure function*** *that does this*. Thus, I begin with this function. Because the phrase "non-frustrating technical failure" is going to come up a number of times in what follows, I am going to give this phrase an acronym, NFTF, to save myself some writing and save you from having to read this long phrase too repetitiously.

A learner will learn something objectively (acquire objective knowledge) only when by doing so this accommodation in his manifold of concepts makes it possible for him to fulfill some purpose of his own. If a knowledge-object serves no learner purpose, the knowledge is "pointless" to the learner and will be dismissed by type-α compensation behavior. What the purpose might be is, of course, extremely variable from learner to learner and a learner might not even be cognizant of his own purpose. A teacher must strive to *seduce* learners' attentions to a focus upon the *lesson object* the teacher intends for them to focus on. By seduction I mean persuading a learner to make an intended lesson object his own *purposive object* (see chapter 10). From the theoretical Standpoint, knowledge of an object means conceptualization of it. The process by which a learner comes to do this is fairly complicated and involves cycles of interaction with the object combined with cycles of judgmentation by which the learner makes accommodations to his manifold of concepts (and perhaps to his manifold of rules as well). Piaget concluded,

> To sum up, the study of cognizance has led us to place it in the general perspective of the circular relationship between subject and object. The subject only learns to know himself when acting on the object, and the latter can become known only as a result of progress of the actions carried out on it. This explains the circle of the sciences, of which the solidarity that unites them is contrary to all linear hierarchy. Furthermore, and most importantly, this explains the harmony between thought and reality, since action springs from the laws of an organism that is simultaneously one physical object among many and the source of the acting, then thinking, subject. [Piaget (1974), pg. 353]

Piaget's findings yielded an empirical description of objective learning phenomena. 'Action' refers here to both physical action expressions *and* mental acts of ratio-expression in pure Reason [Piaget (1975)]. He provided a limited mathematical explanation of the process, which he called a type-II interaction [Piaget (1975), pp. 36-54]. Figure 2, presented here merely for illustrative purposes, is Piaget's diagram of the structure of a type-II interaction process. Mental physics later provided a deeper causative explanation for this finding [Wells (2006), chap. 9].

It is not vital for purposes of this treatise to explain figure 2 in technical detail, although technical understanding of figure 2 is necessary for *scientific* teaching practices. I refer the reader to the references cited in the figure caption for a technical treatment of type-II interactions. What I would like you to understand for now is that objective knowledge acquisition is cyclic process.

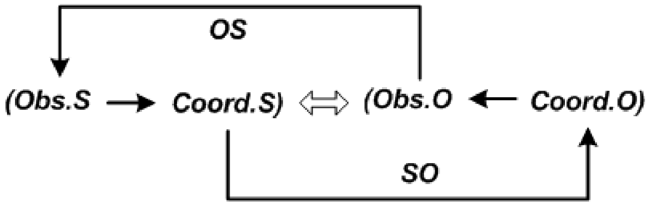

Figure 2: Piaget's type-II interaction structure. Refer to Piaget (1975), pp. 36-54, and Wells (2006), chap. 9, pp. 754-769 for the technical explanation of this figure. The figure depicts concurrent multiple *cycles* of interactions between the subject (*Obs.S*, *Coord.S*), the object he is interacting with (*Obs.O*, *Coord.O*), and the subject's observation schemes and anticipation schemes for these interactions (*OS*, *SO*).

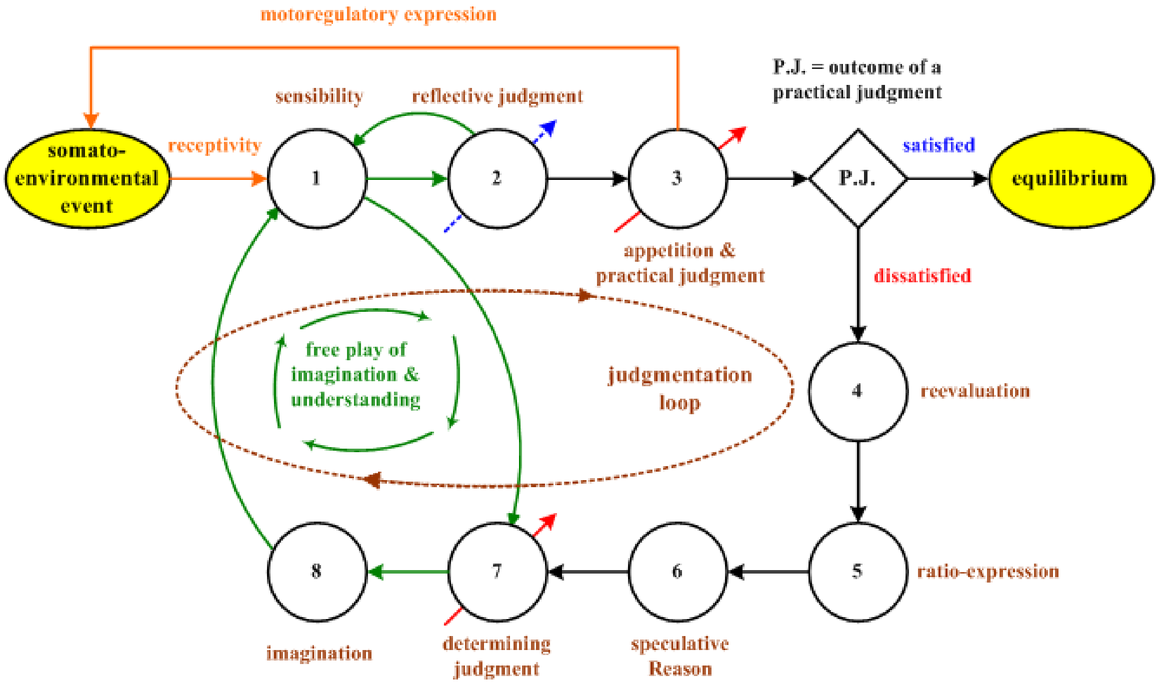

Figure 3: Logical flow of the synthesis in the motivational dynamic of the learner. Accommodation of perception occurs by means of the cycle of free play of imagination and understanding.

Merely interacting with an object is not enough. For learning to occur, the learner's *anticipations* must be momentarily gainsaid in order to produce a disturbance to his equilibrium. If this does not happen, he merely assimilates the object into his schemes. Accommodation of his manifold of concepts does not occur in this case, thus no learning occurs. A *failure* is perception of lack of congruence between an appearance of a phenomenal object and an appearance of an Object of anticipation presented in sensibility through reproductive imagination. Motivation is accommodation of perception; a learner is motivated to learn by the cognitive dissonance lack of congruence between actual perception and anticipation produces (figure 3). To be a NFTF event, the learner must be able to soon resolve this lack of congruence and eliminate the disturbance to his equilibrium by means of type-β compensation. If he cannot then the failure becomes a *frustrating* failure and he makes type-α compensation (ignórance) the means by which he recovers his equilibrium. It is while the learner is groping to reequilibrate himself that he is open to perception and conceptualization of new facts and concepts and *that* is when a teacher can intervene to guide the learner and teach the lesson object the lesson is intended to teach.

I don't wish to sound too glib about this. It's not an easy thing to do, especially in a classroom filled with many learners. But the most common method of lecture instruction can be summed up by saying one factoid after another is introduced to the learners *and only then* is an attempt made to demonstrate the usefulness or the pertinence of these things. For the majority of learners, this comes too late. They have already ignored the factoids. Some learners will recover from this, if not too much time has elapsed, but many will not. Put simply, the most common lecture method tries to introduce the factoid *and then* get the learner interested in it. What lecture method has to do instead is "get the learner interested" by disturbing his equilibrium *and then* provide the factoid, concept, or idea *that he can use to eliminate the disturbance*. Psychologically, *the order of these steps does not commute*. It takes a NFTF event to *provoke* learner interest.

The error in instructional ordering is the principal reason for the failure of the "object lesson method" tried in the 19th century under the misleading label 'Pestalozzianism' [Cubberley (1919), pp. 269-270].[6] As an illustration, I still have un-fond memories to this day of my 9th grade earth science class. Our teacher tended to 'teach' earth science by telling us *ad infinitum*, "This kind of rock is a such-and-such. This kind of rock is a so-and-so. This kind of rock . . ." It was a mind numbing time of being forced to listen to him endlessly talk about rocks and dirt. My friends in civil engineering today tell me rocks and dirt are endlessly cool and interesting; I'll just take their word for that. The instruction I received back then was neither cool nor interesting. The method of the traditional system gives pupils reasons to attend classes (do this or you'll have to go to summer school) and to sit for exams (do this or you'll have to re-take the course), but quite often pupils are not given a reason to actually engage with the subject-matter and learn about it. The NFTF function is the means to give them an actual motivational stimulation to do so.

For example, some event or phenomenon can be presented and the learners then asked to explain it. If the lesson is well prepared, they won't be able to but they can be drawn into the curiosity of it all. *Then* the key concept is introduced and the puzzle is worked out. Subsequent lessons, involving the same concept-object, are used to make the concept *mobile in its applications*. In-class exercises and homework exercises further continue and reinforce the process.

This is the essence of the NFTF function of intellect education. Lakatos' method of "proofs and refutations" from chapter 14 is a variation on this theme. The NFTF function is based on learner-centering of instruction instead of job-skill or career centering of instruction – the latter centerings being irrelevant to the purposive objects of young pupils (chapter 10, figure 3).

2.2.2 I turn next to the **heuristics of technique function** of intellect education. The aim of this function is cultivation of the learner's development of heuristic technical procedures for finding solutions to technical problems and making discoveries about dead-matter phenomena. A learner makes such a Self-development in a definite temporal order. First must come development of practical maxims in his manifold of rules. The learner is unconscious of these rules because the manifold of rules is isolated from cognitive sensibility. At one time psychologists briefly speculated that a human being must be conscious of some representation of his motoregulatory expressions. This was called the hypothesis of 'feelings of innervation.' It was refuted on grounds of both empirical evidence and epistemological considerations that showed such feelings were in no way necessary to explain voluntary movements [James (1890), vol. II, pp. 503-521]. Since James' day, advances in our knowledge of neuroscience and brain organization has greatly refined and extended our knowledge of neurological linkages between the neocortex and motor pathways (figure 4) [Sherman & Guillery (2006)]. These findings tend to affirm many of James' early qualitative guesses about neurology relationships involved in voluntary movement.

Cognizance of practical rules moves "from the periphery to the center" (as Piaget put it) by representation of the person's observations of goals and results and his sensations of kinaesthetic feedback via ascending sensory afferents. Descending motor efferents, in contrast, are not fed back to cognition-related brain regions (figure 4). Scheme conception is first conceptualized in the form of presentative scheme concepts in the manifold of concepts and is later generalized in the form of procedural schemata (chapter 10). Piaget and his coworkers have provided many very interesting behavioral observations that experimentally support this theory [Piaget (1974)].

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[6] It is also, by the way, the principal cause of the bad rap history gets because of the way it is usually taught from grade school through high school and the way many history textbooks are written. I was in the campus bookstore one day and I happened to see a young girl (she looked like she was middle school aged) with a woman (apparently her mother). They were in the college courses' textbooks area of the bookstore. It is not too especially rare an event to encounter 'prodigies' on a college campus so I didn't give it too much thought that a little girl would be shopping for textbooks for college courses. A short time later, over in the non-textbook area of the store, I chanced upon them again just in time to hear the little girl saying to her mother, "This is like a history book only interesting."

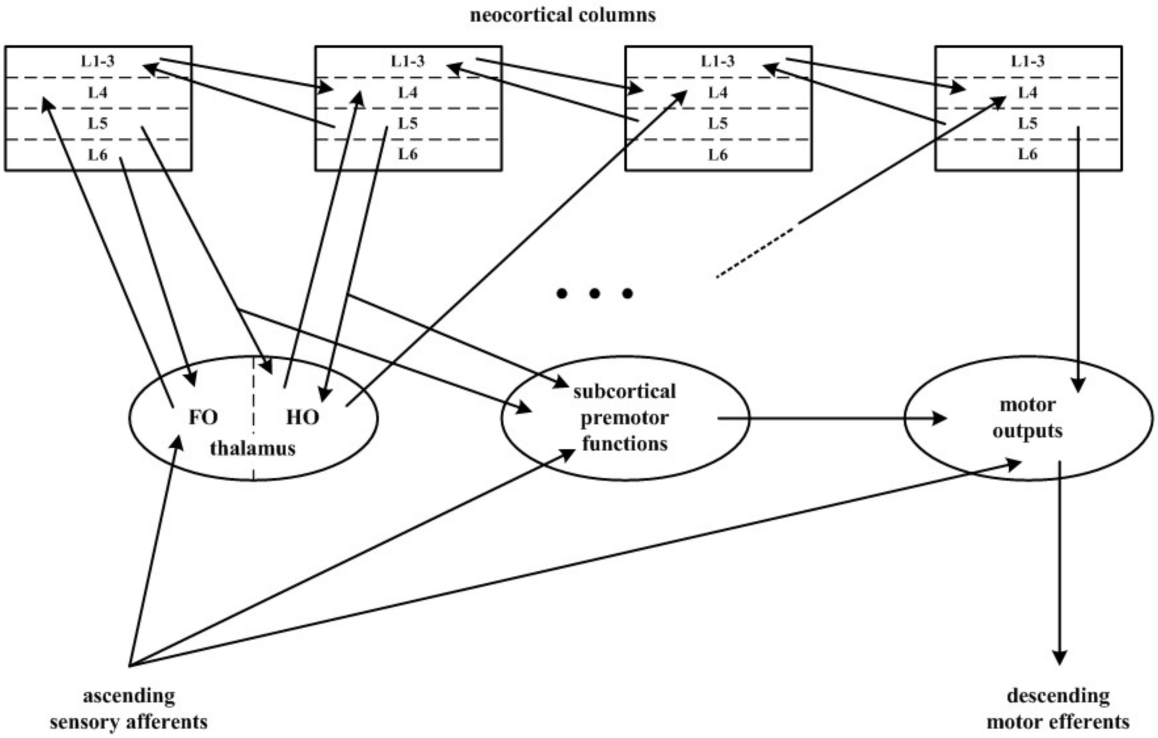

Figure 4: Schema of anatomical organization of thalamocortical-motor pathway linkages in the brain. The neocortex is known to be involved in cognitive functions. The thalamus, subcortical premotor, and motor outputs structures in the brain are not immediately involved in consciousness of cognitive representations. FO = first order thalamic nuclei; HO = higher order thalamic nuclei [Sherman & Guillery (2006)].

Cultivation of the learner's development of his practical rule schemes belongs to the functions of corporal education already discussed. It falls to the heuristics of technique function to cultivate learner cognizance of his schemes and then his improvement and refinement of them. Intellectual *Personfähigkeit* is the power of a person to realize or attempt to realize the objects of his appetites by means of his knowledge, intelligence, and judgment. Subsisting in the latter two is his ability to judge when he needs to add to his knowledge of objects in order to realize his purpose. The heuristics of technique function cultivates the learner's capacities of intelligence and judgment and so serves to perfect his intellectual *Personfähigkeit*.

All learning is a consequence of the person seeking to reestablish practical equilibrium. The act of learning in regard to intellectual *Personfähigkeit* is construction of new concept structures in the person's manifold of concepts and new practical maxims of thinking in his manifold of rules. The latter are *essentially* expressed by ratio-expression, which is not displayed to an observer, along with motoregulatory expressions that might or might not exhibit the presence of the activity of these maxims to an observer[7]. When reestablishment of equilibrium requires a person to solve some problem that is new to him, his problem solving action employs a *groping* for equilibrium (which is the problematic Modality in the motivational dynamic; see figure 5). Put another way, the person seeks a solution that satisfies his necessity for achieving a state of equilibrium. A heuristic is a directed procedure for discovering such a solution. The instructional function aims to cultivate learner development of heuristic techniques.

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[7] When you see a person sitting quietly and, say, stroking his chin, you can infer that he is enacting maxims of thinking, although what these maxims are expressing via ratio-expression you will not know. When you see a person to whom you are talking looking at you with an impassive expression on his face, you will not generally know if he is even listening to you, much less thinking about what you are saying.

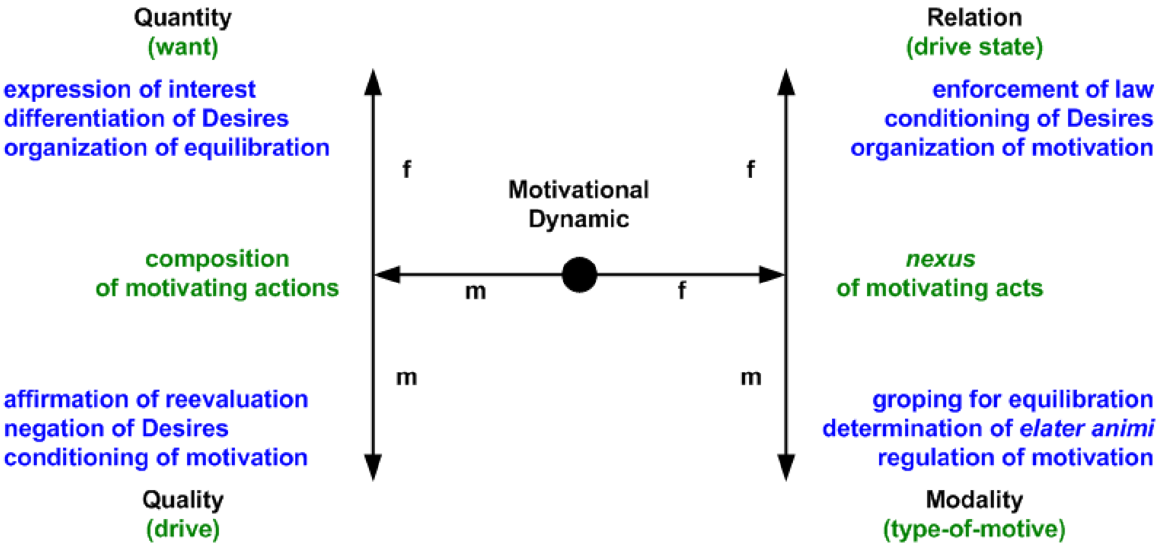

Figure 5: 2LAR structure of the motivational dynamic.

What *téchne* can instruction use to cultivate such a development? One of what I regard as the best innovations proposed in the NGSS framework is its idea to blend "engineering" instruction with "science" instruction in the framework. The editors who produced this document were hindered by very fundamental misunderstandings of what "engineering" is and what engineers do, and these misunderstandings are fatal to the framework they propose[8], but nevertheless they did plant an important new seed for reforming science education. What is this seed and into what can it be grown?

Every branch of engineering began as a technical art and was developed into a science by gradually incorporating progressively more extensive scientific theories into the art. This is recognized in the community of engineers and is why one hears them refer to something called "the state of the art." What is perhaps less widely recognized by the community of scientists today is that *all* the physical-natural sciences, including physics, chemistry and biology, *also followed this same developmental pathway*. Science historian Thomas Kuhn wrote,

> In the absence of a paradigm or some candidate for a paradigm, all of the facts that could possibly pertain to the development of a given science are likely to seem equally relevant. As a result, early fact-gathering is a far more nearly random activity than the one that subsequent scientific development makes familiar. Furthermore, in the absence of a reason for seeking some particular form of more recondite information, early fact-gathering is usually restricted to the wealth of data that lie ready to hand. The resulting pool of facts contains those accessible to casual observation and experiment together with some of the more esoteric data retrievable from established crafts like medicine, calendar making, and metallurgy. Because the crafts are one readily accessible source of facts that could not have been casually discovered, technology has often played a vital role in the emergence of new sciences. [Kuhn (1970), pp. 15-16]

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[8] Perhaps the most important misunderstanding in this regard contained in the NGSS framework document is that its editors use what psychologists call the rational model of problem-solving [Leavitt (1972), pg. 64] to describe how engineering works. This is documented in appendix I of National Research Council (2012). There are two fundamental problems with this: (*i*) the rational model does not describe how people actually solve problems; and (*ii*) engineering does not even attempt to do things this way. The three editors of the NGSS document were a particle physicist and two educologists, so it is at least understandable that none of them would know much of anything about engineering. Their psychology error is less excusable.

It is vainglorious hubris to pretend the divers sciences developed in any other way than this. No science develops because of brilliant insights of a genius founder whose innate talents lie beyond any capacity possessed by other people. Newton was not practicing false modesty when he wrote, "If I have seen further it is by standing on the shoulders of Giants."

One good reason for teaching science is, of course, to avoid the clear disadvantageousness of having every person start from scratch as if there were no existing base of knowledge from which development of his tangible *Personfähigkeit* could be accelerated. The slow pace of technological change and the even slower pace of social change in Societies from the beginning of the historical record through, arguably, the 17th century demonstrates one of the more pronounced effects that the absence of science education has on Societies. This can be called "the utility argument" for public science education. However, overlooked in this argument is the basic fact that for a child his knowledge of science *always* 'starts from scratch.' Science instruction *téchne* must recognize this fact explicitly. For that reason, *téchne* developers are well advised to pay attention to the historical routes taken by the developed sciences because a child's understanding of science will, by psychological constraint, have to follow an analogous route. Present science instruction by and large ignores this psychological aspect of science-learning. The NGSS likewise ignores it.

The utility argument, as it is traditionally reflected in institutions of education, presupposes that, figuratively speaking, knowledge can be poured into a child's head like beer can be poured into a glass. It is a presupposition and an attitude in the way science has traditionally been taught in American schools that fosters a crippling reliance on memorization. Memorization is useless as a tactic of pedagogy in science because the meanings of what is memorized remain "external" to the learner and do not cultivate his abilities. Human beings learn from the particular to the general but traditional science instruction attempts to reverse this order. When I was teaching I saw every day the crippling effects this has on engineering students. It is worse for students in other majors.

A "how it is done" approach to science instruction, as this has been practiced, leads at best to learner development of rote schemes without cultivating an ability to deal with things that do not directly assimilate into these schemes. It is very dubious that such an education is sufficient even to sustain Order in a Society and it is almost beyond reasonable doubt that it is insufficient to promote Progress. For example, the scientific evidence that global climate change is a real and present phenomenon is beyond reasonable doubt to people who understand science and scientific methods, yet there are many Americans who think the question is not yet answered. For another example, it is beyond reasonable doubt that evolution is a real phenomenon, yet teaching learners about evolution is vehemently opposed by particular religious factions[9]. The first is an example of a threat to Order in Society, the second an example of a blockade to Progress.

An antidote to these ills is instruction cultivating learner heuristic techniques using science as the *materia circa quam* of technique development. Cultivation of this ability prepares a citizen for later professional study in an established field of science or engineering if he so chooses. More importantly, it is propaedeutic for *any* citizen's ability to develop a *new science* as needed for meeting *new challenges* that continually arise and confront all Societies. Despite the particular technical differences that can be distinguished among established sciences, one factor is utterly common to all of them: science is practiced by human beings and scientific *innovation* is always the product of the groping Modality of the motivational dynamic (figure 5).

The specifying concept for development of science instruction *téchne* is the idea of *teaching science by cultivating learner craftsmanship in the art of discovery*. This phrase, the art of discovery, requires some explanation because this phrase has divergent usages by various people.

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[9] Notwithstanding the label "theory of evolution" that is widely employed, evolution is a *fact*, not a theory. It has been demonstrated innumerable times in the laboratory. *Natural selection* is a theory. That so many Americans do not know the difference between fact and theory displays our national illiteracy in science.

Many of them are members of the community of visual artists (e.g. painters and photographers). One of the term's usages argues that close union with the fine arts can energize the technical arts through renewal of the wonder of past achievements. Timothy (2010) presents such an argument. Divers other usages are also made of the phrase, which leaves it without a singularly understood specific meaning. The meaning I intend for it in this chapter has the following explanation.

Science practice seeks accurately descriptive models of and causative explanations for natural phenomena. The former involves the use of mathematics with careful identification of principal quantities of mathematics to tie mathematical *noumena* to the appearances of natural phenomena. The latter seeks to understand conditions under which the natural phenomena can be anticipated to occur. In its more perfectly developed stages of understanding, a science doctrine is a doctrine of *necessitated* relationships, i.e., relationships that must be held-to-be-necessary *if* the *noumenal* laws of nature proposed in the doctrine are true. This is nothing less than a metaphysical requirement placed upon the practice of science. Newton stated the spirit of this requirement as Rule IV of his "Rules of reasoning in philosophy":

> In experimental philosophy we are to look upon propositions collected by general induction from *phænomena* as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other *phænomena* occur, by which they may either be made more accurate or liable to exception.
>
> This rule we must follow, that the argument of induction may not be evaded by hypothesis. [Newton (1726), pg. 321]

Newton's rule is properly to be regarded as a rule of necessitation, i.e., a rule for when a scientist is to hold something to be necessary. As for "necessity" itself, Piaget tells us,

> The principal results of the present research can be summarized in the following three points: (1) Necessity pertains to the compositions carried out by the subject [the person who holds something to be necessary] and is not an observable datum inherent in objects; (2) it is not an isolated and definitive state, but the result of a process (necessitation); and (3) it is directly related to the constituting of possibilities that generate differentiations, whereas necessity is related to integration – hence the two formations are in equilibrium. [Piaget (1983), pg. 135]

In natural science, as distinct from logic and mathematics, necessity in explanations of phenomena is made necessary by notions of causality & dependency in the connections between concepts in the manifold of concepts [Wells (2009), chap. 5]. *How* a learner makes connections of this kind depends not only upon his structure of object-concepts but also upon stages of development in his capacity to conceptualize possibilities [Piaget (1981)]. The interdependency of these two psychological factors produces some very interesting empirical phenomena of developmental psychology. Piaget documented three distinguishable stages in development of childish concepts of physical causation, each one corresponding to one of the general stages of preoperational thought, concrete operations, and formal operations [Piaget (1930), pp. 275-279].

Curriculum design for science instruction must take these stages into account and also must coordinate science instruction with mathematics instruction (because *models* are mathematical). With regard to childish concepts of causation, Piaget found,

> Before the age of 7-8 the child seeks, as far as possible, to eliminate chance from nature. The very way he formulates his "whys" shows that for him everything has a reason, even when to us it seems fortuitous and contingent. Now, whatever contradicts this conception provokes, by the mere fact of doing so, the maximum of curiosity on the part of the child. And this is why we find the child trying to find the reasons or justifications for a whole

> number of facts which for us are inexplicable because they are due to chance . . .
>
> To conclude, during the first period the necessity of law is entirely moral, and physical necessity is simply the lining as it were of this moral necessity, i.e., it is simply dependent upon the force and authority of the masters of nature. . . . Corresponding to the confusion between natural and moral law, there is, during this first stage, a complete absence of generality in the laws of nature. . . .
>
> During the second period, on the contrary, we see two processes at work which are complementary to each other and take place between the years of 7-8 and 11-12; on the one hand, moral necessity and physical determinism become differentiated, and on the other hand, law becomes general. . . . But the clearest index of all is the appearance of the idea of chance. At about 7-8 the child begins to admit that there are things which serve no particular purpose and events due solely to chance encounters. . . . It goes without saying that moral necessity is not changed into physical determinism at a stroke. Up to the age of 11-12, many natural laws are still thought of as moral. . . . As to the generality of law, it naturally grows in proportion as moral necessity declines. . . .
>
> Finally comes the third period, which sets in at about 10-11. During this period, the generality of law naturally takes deeper root. But what becomes of necessity? . . . [A] paradox attends the evolution of law in the child: as the generality of laws increases their necessity grows less (in so far as this necessity, as during the first two periods, is moral). For as the child abandons the idea of moral necessity for justifying laws, he is faced with a mere generality of fact that is, however, devoid of any foundation whatsoever. When we ask a child why water goes down whereas smoke goes up, he can answer that heavy bodies fall whereas light bodies rise, which is certainly a general law; but when we question him further as to why this is so, he can answer nothing. [Piaget (1930), pp. 275-278]

One of the things instruction *téchne* must take into account is a vulnerability in the second stage that enters because of the child's acceptance of the idea of chance. In science a "chance event" loosely means coincidence and *practically* means no phenomenal connection between "chance events" need be sought. To a child, however, admission of the idea of chance *is a ground for ignoring things not immediately reducible to explanation*. The "maximum of curiosity" Piaget mentioned in the first stage can quite easily shift into a ***lack*** of curiosity in the second. Again, reequilibration is often most easily achieved by ignórance (type-α compensation) so long as it is possible for ignórance to provide a satisficing solution. I think the fact that ignórance leads to ignorance requires no lengthy explanation here. The second stage is a most crucial period for science cultivation in pupils. I think the NGSS framework fails to recognize this criticality.

A moment ago I said science seeks accurately descriptive models of and causative explanations for natural phenomena. When such a model or explanation is found that no one knew about before, a "discovery" is said to have been made. Most scientists revere discoveries but at the same time scientists are somewhat surprisingly vague or ambiguous about precisely what is meant by the term "discovery." It is not used as a *technical* term in science. Rather, its usages follow dictionary conventions and it is used in connotations of both (*i*) the act of discovering; and (*ii*) the thing discovered. The verb "discover" is taken in science to mean "to find out; to learn of the existence of." Even philosophers are surprisingly casual in the way they take "discovery" for granted. Given the way discoverers and discoveries are venerated by scientists, this is a rather peculiar state of affairs. What *is* a discovery?

A "discovery" is something that seems to hover somehow between the thing discovered and the person who discovers it. A discovery is not regarded as part of the object discovered, nor is it regarded as something inherent in the person said to *make* the discovery. In this context, what Piaget said of "structures" in the sciences can up to a degree be applied to the notion of discovery:

> The third major problem which arises in comparative studies is that of the nature of the

> structures arrived at, i.e. whether they constitute simple 'models' in the service of theoreticians or whether they should be considered as inherent to the reality under study, in other words as structures of the subject or subjects themselves. This question is fundamental because in the eyes of authors critical of structuralism the latter is merely a language or a computing instrument which refers to the observer's logic but not the subject. This problem is often raised even in psychology, where experimentation is relatively easy and where one can in certain cases be fairly sure that structure reaches down to the underlying explanatory principle of phenomena, in a sense which recalls what the philosophers call the 'essence', but with the addition of an undeniable deductive power. But in disciplines where experimentation is difficult, even in the broadest sense as in econometrics, experts often stress the divergence they see between the mathematical 'model' and the 'experimental design', a model without sufficient relationship with the concrete being no more than a play of mathematical relations, whereas a model which adopts the details of the experimental design can claim the status of a 'real' structure. It goes without saying that in most situations the models used in the human sciences are placed, still more than in physical and even biological models, halfway between the . . . theoretical design partially related to the observer's decisions and the actual organization of the behaviors to be explained. [Piaget (1970), pg. 25]

In a wide sense of the word, anything any person learns that he did not know beforehand is a discovery *to him*. It happens often enough that a researcher submits a paper to a journal only to learn from the reviews he gets back that his discovery had been discovered previously by someone else whose report on it was published decades earlier in some journal he had never heard of. That he "discovered it independently" years after someone else had does not change the fact that *to him* what he learned was "a discovery." It merely wasn't a "novel" discovery.

A discovery, then, always *co*-involves a discoverer and a thing discovered. There is something conceived to be true of an object *and* a person who conceives it. This co-dependency of a thing discovered and a discoverer points us to a *judicial* answer to the question. From the judicial Standpoint, a ***discovery*** is *a new state of understanding-a-previously-unknown-truth about some object of Nature which is produced by action(s) taken by the person who understands*. The person who understands is called the discoverer and what he understands is the thing discovered.

For education institution this distinction is not a mere matter of semantics. *Every learner is a discoverer* regardless of whether the thing he discovers has been known to others for centuries or is something no one ever knew before. Every newborn infant ***makes*** discoveries and, indeed, a child is an eager little discoverer right up until the time when his educational environment drives the pleasure of discovery from him so thoroughly that he no longer actively seeks to discover.

Perhaps it is unnecessary for me to say that our institution of public education must put a stop to discouraging discovery. Its role, rather, is to seek to enhance learners' skills in making them and to teach learners methods of doing so that improve the likelihood the concepts he constructs are true (that is, the concept is congruent with actual experiences of the object). An art is the disposition or modification of things by human ability in order to fulfill an intended purpose. A craft is the practice of some special art. Skill is ability to practice a craft. This means that "discovery" is an art (because it changes one's understanding). Instruction seeks to cultivate in the learner the greatest degree of skill possible in his *craft* of discovery, and this is the aim of the heuristics of technique function in public instructional education. The degree of the effectiveness in its instruction is properly gauged in terms of the degree to which a learner's understanding is *constituted as a science of what-it-is that he understands.*

From the perspective of Society, science education is not so much about teaching science as it is about cultivating scientists. The utility of any one science waxes and wanes in time but the need to construct new sciences to meet new challenges is socially perennial. Existing sciences are *materia circa quam* for this cultivation *in addition* to being ready sources of *materia ex qua* for cultivating learner tangible *Personfähigkeit*. Put into plain English, existing sciences are matter-around-which lessons are formed and also matter-from-which tangible skills are built. The first serves intelligence-building for the learner, the second serves the commonwealth of Society.

Instruction for the heuristics of technique function must proceed by: (*i*) cultivating in the learner the ability to *conceive possibilities*; (*ii*) providing the learner with practice in fact finding as part of his groping to solve concrete problems involving dead-matter objects of Nature; and (*iii*) cultivating the learner's skill in constructing systems of explanations for natural phenomena. Conception of possibilities is an essential first step for building any science because without the differentiations that possibilities produce the person's understanding is restricted by what Piaget called pseudo-necessities and his thinking and reasoning remain egocentric [Piaget (1981)].

Practice in fact finding for specific and concrete physical problems and questions is the active learning element of science instruction. The traditional method of instruction has been to present an *answer* without giving the learner an opportunity to learn what the *question* is. The answer is, to the learner, meaningless without him first *understanding* the question. In some ways, this part of the instruction *téchne* is reminiscent of the old 'projects method' favored by the PEM. There are, however, differences that are foundational for the effectiveness of instruction.

The existing science doctrines provide a wealth of very specific phenomena for which science has explanations to offer. *These phenomena* must be used for 'mini-projects' of exploration *and the teacher must guide the learners' discovery processes* so that when the learner makes his discovery what he discovers is also what the doctrine of science teaches. The fatal weakness of the old PEM projects method was that it was focused on a narrow task-to-be-accomplished (e.g., building a wagon) and not on building knowledge of a doctrine. It was childishly naïve of PEM reformers to assume the latter would automatically come out of the former. Instructional guidance must not stop with mere finding of facts but, rather, it must also be concerned with organization of facts within a factual schema[10] in such a way that the learner's organizing activities give rise to construction of schemes-of-organizing. The teacher must understand a science's schema and actively intervene to guide the learner to it in order to ensure appropriate outcomes are achieved. This means the teacher must be knowledgeable of what the pertinent schemata and outcomes are. A person who does not understand the doctrine of a science cannot teach that science[11].

Finally, cultivating learner construction of systems of explanations means cultivating learner knowledge of what 'models' are, how to apply mathematics to make models, and methods of ascertaining the level of confidence one can have in one's understanding, e.g., what statistics calls t-tests and F-tests [Ott (1977), chaps. 5, 12]. A useful contribution of the NGSS framework is its call for explicit incorporation of modeling as part of the science curriculum. However, there is a weak point and a caution involved here that is not due to the NGSS commission's work but rather to the poor state of understanding the craft of modeling that permeates the science community.

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[10] A schema is a rule governing the form of a synthesis in the manifoldness and order of the parts. A schema is not the same thing as a scheme.

[11] I will make the observation that the NGSS is organized around what it calls "disciplinary core ideas." By doing so it makes some fatal fundamental errors. First, what it calls "core ideas" are *not* "core" ideas of the existing science disciplines. They are concepts of *noumena* that do bind the doctrine together but are of such a remote and abstract character that *learners cannot use them to learn how to practice a science*. If you teach a pupil that "energy makes it go" you teach him ***nothing***. For one thing, "energy also makes it stop." That which explains everything explains nothing; if we were to settle for that we could accomplish the aim far quicker by attributing all phenomena to the will of God. For another thing, "energy" is a mathematical object remote from sensuous experience; to comprehend its idea one must first understand many physical phenomena and the NGSS fatally underemphasizes the phenomena science seeks to explain. At the same time, appendix F of National Research Council (2012) introduces eight "practices" of science (and engineering), and these practices *are* properly pertinent and central to science instruction.

Models are essential parts of every scientific theory. Indeed, one cannot have a real theory without a model. Paradoxically, models and model-making are too much taken for granted by most scientists. Modeling is a craft in its own right and one that is not explicitly taught at any level of public education save for a few isolated courses here and there put together by individual professors and, to a limited degree, in statistics courses. My own observation of college students, both undergraduate and graduate students, in engineering, physics, and biology over the course of the past thirty years has been that students are barely aware that they even use models or that the theories they learn are model-based. They are not trained in how to construct models and most are unaware that a scientist's research work largely revolves around designing and inventing models to explain phenomena. Practicing scientists and engineers, at least at the PhD level, do eventually come to develop model-making skills as a result of their professional practices, but it cannot truthfully be said that most scientists or engineers come to practice the craft of model-making as a *discipline*. The partial exceptions to this picture are found mainly in biology and statistics. Model making *as a complete and disciplined craft* tends to be the exclusive province of a few system theory specialists, where the craft, in a piecemeal fashion, tends to go by the names "system identification" and "parameter estimation." The prospect of being able to remedy the general state of illiteracy in regard to models and modeling is one of the attractive features of the NGSS.

A *model* is a representation that mirrors, duplicates, imitates, or in some way illustrates a pattern of relationships in data or in nature. A *complete* model always consists of two distinct parts: (*i*) a qualitative model; and (*ii*) a quantitative model [Wells (2010), chap. 1, §2.1]. A *qualitative model* is a model resulting from an analysis of the identity of the constituent parts of a system. A *quantitative model* is a model resulting from an analysis of the estimation of the amount or numerical value of each of the constituent parts provided by the qualitative model. The quantitative model augments the qualitative model with precise relationships that apply to and among the constituent parts. Quantitative models always involve making approximations; skill in model-making is skill in judiciously determining what approximations can and should be made. This aspect of model-making is inherent in the earlier Feynman quote in §2.1 of this chapter. A good introductory overview of model-making and how it is applied in science is given in Weinberg (1975). Weinberg's presentation does not require the reader to have very much mathematical background. The treatment he presents can, with age-appropriate modifications, be used to develop lessons in models and model-making for a K-12 curriculum. The presentation must be a progression. The youngest pupils should have their introduction to it presented through putting together model kits. The old Lincoln Logs® kits, model car kits, and the Illustrated Man® human anatomy kit come to mind in this regard. There are many other such kits available. Even puzzle maps, e.g. a puzzle map of the United States, are very useful for modeling instruction. As the child progresses through the grade levels, mathematical modeling proceeding from qualitative modeling must gradually be added to the lessons. Model-making in science is always carried out heuristically (because it involves finding *appropriate* approximations), and so models and model-making fall under the heuristics of technique function of intellect education.

2.2.3 The last function of intellect education for science is the **civics planning function** (inclusion in the curriculum of exercises that stimulate the learner's development of procedural schemata applied to technical objects). The adjective "civics" in the name of this function refers to how the individual determines his actions in regard to constraints and expectations for his behavior as a member of a Community (in this case, the community of scientists).

This function can be regarded as a synthesis of the earlier two functions. As the learner gains knowledge of objects through the non-frustrating technical failure function and develops heuristic discovery approaches, it becomes increasingly possible for him to systematize his approach to problem solving for discovery and design. I think it is perhaps obvious enough that before a learner can make his problem solving approaches systematic he must first have a basis in experience to draw upon. Put another way, one cannot make anything systematic unless one first has something to systematize. The earlier two functions provide this but do not do so in an organized fashion. Each individual experience juxtaposes the items of his knowledge and does so in an *ad hoc* fashion. The power of scientific knowledge lies in its organization, and the learner must synthesize what he has learned piecewise into a unity of paradigms and practices. At the same time, the way in which he undertakes discovery or invents solutions is not isolated from the influence of others in his Society. Some solution methods are "acceptable"; others are not. In professional societies, a "Code of Good Practice" is an example of the sorts of constraints members of that society operate under within the community of their peers. For instance, the Engineers' Creed adopted in 1954 by the National Society of Professional Engineers pledges the members of this professional society

> To give the utmost of performance;
> To participate in none but honest enterprise;
> To live and work according to the laws of man and the highest standards of professional conduct;
> To place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above all other considerations.

Civics planning function exercises are aimed at cultivating the learner's development of problem solving techniques within social constraints on his actions. Their training in problem solving technique is the primary thing that distinguishes the problem-solving ability of a scientist or an engineer from people who have not received this kind of training. To a degree it sets out an individual's "specialization" inasmuch as good problem-solving ability in one field does not necessary imply good problem-solving ability in others. Procedural schemata he develops from presentative schemes, which he conceptualizes through heuristic techniques, lay the foundations for what the NGSS refers to as "practices." The NGSS framework identifies eight of these:

1. asking questions and defining problems;
2. developing and using models;
3. planning and carrying out investigations;
4. analyzing and interpreting data;
5. using mathematics and computational thinking;
6. constructing explanations and designing solutions;
7. engaging in argument from evidence;
8. obtaining, evaluating, and communicating information.

[National Research Council (2012), appendix F]

Although the NGSS framework attempts to define a distinction between science and engineering in this list of practices, in fact this is a fictitious division and these practices apply equally to both.

Practices 4 through 8 implicitly call for the learner to apply simple statistical analysis methods in order to properly judge data, possible explanations, and evidence. Instruction in this should begin as soon as the learner has developed to the stage of formal operations. I am not saying that a formal course in statistics is necessary at the middle school or high school level of public education. There are simple and easy-to-do statistical hypothesis tests that can be carried out with a minimum of mathematical training and can be applied to small data sets. Chief among these are what statisticians call t-tests and F-tests [Ott (1977), chaps. 5, 12]. There are two points I wish to make about these tests.

The first point is that the learner should learn how to do these tests without the aid of pre-prepared computer programs so that he will understand what it is exactly that is being computed and how it relates to the *confidence* he can have in the validity of his judgments. Toward this end, the confidence standard used in science and put to the proof by years of empirical experience should be used. Specifically, the standard is to test empirical data at what is called "the 0.05 level of significance." This more or less means that a statistical evaluation has less than about a one-time-in-twenty chance of being wrong (finding out something that isn't true). It happens from time to time – whether due to zeal for some political or social cause or from ignorance of statistics – that even some scientists will "twiddle" with the level of significance in their analysis to get a conclusion they *want* to see rather than one the data actually supports. This is, quite correctly, called "junk science" and it is professional malpractice. It is a subtle trick to get away with lying with statistics and to deceive the public by taking advantage of the appalling level of ignorance about statistics that presently characterizes the situation in America.

My second point is that real data is subject to finite precision in the ability of measuring instruments to measure it. Just because an instrument might have a digital readout with eight digits displayed is not an implied warranty that its readings have eight digit accuracy. The precision with which data is known is limited by the precision of the measuring instruments. That is why computer programs for doing statistical analysis can be very misleading. I have known very bright and honest students to innocently claim a level of certainty in their findings orders of magnitude better than the accuracy of their instruments permit just because of a computer printout. Computing *never* puts in information not contained in the data originally.

The findings of empirical science are never absolute. That is why it is necessary to have a *standardized gauge* for assessing conclusions. The 0.05 level of significance standard I noted above is the one that years of experience in the practice of science have coalesced around. When you hear on the news or read in the paper that researchers at such-and-such an institute have "found" this-or-that, it only means that they are confident about their findings to the level of significance professionally used by that community in stating research findings.

It is crucial that when one evaluates data one is constantly reminded that empirical data never provides *certainty*. The best science can ever do shares a standard with American legal practice, i.e., the best empirical science can ever do is establish something *beyond **reasonable** doubt*. There is a big difference between reasonable doubt and unreasonable doubt. The level of significance standard gauge establishes a standard for defining what "reasonable doubt" is in science.

The civics planning function makes project-centered learning activities for science education different from the "projects method" of PEM reforms. PEM projects methods contained no element of systematizing, organizing, and generalizing what the pupil learned by carrying out specific projects, and this was perhaps the best justified criticism leveled at it. Instruction *téchne* for the civics planning function perhaps requires more active guidance and role model behavior by the teacher than any other instructional function of science education.

§ 2.3 The Tangible Education Functions

The tangible education functions pose special difficulties with regard to their relationships to science education. This is not because these functions are unimportant to science education; they are quite important. It is because they do not really "fit" inside science education; *science education instead fits inside them*. Furthermore, because these functions have long been neglected in public education, there are few models or examples lying readily at hand for teachers to draw upon as they research and develop much-needed new *téchne* for science education.

In some ways the situation points out a problem with our traditional framework classifications. Educology has not fully recognized that the tangible education functions require a unique framework (or perhaps framework*s*) because the sort of learner cultivation they call for is ***mobile***. By this I mean they touch upon all possible occupations and economic situations in a Republic. There is perhaps no other aspect of public education more in need of careful *scientific* development than the aspect covered by the functions of tangible education.

This does not mean educology has always neglected these aspects. That assertion is provably false and various education reform movements in the United States demonstrate this. Particular examples include the trade school movement, the vocational education movement, the business education in high school movement, the manual training movement, and the agricultural school movement [Wells (2013), chap. 9, pp. 295-296]. The error common to all these movements, as well as to occupational PEM reforms, was that they were all focused on job skills – an error that is still a major factor in the way most Americans view public education today. A focus on job skills *must* fail because of two principal reasons: (1) it is not within the realm of any practical possibility that public schools could adequately impart job skills because of the sheer number and variety of occupations; and (2) the job skills point of view inherently adopts a view that a profile of occupations is a *stagnant* feature of the socio-economic conditions in a nation. Only arrested Societies exhibit stagnant occupations. *Capital skill*, not job skill, is the correct social-natural and occupation-oriented object of tangible education [*ibid*., chap. 9, pp. 301-304]. Capital skills are *mobile* skills because capital skill serves tangible *Personfähigkeit* in *every* occupation.

Tangible education primarily emphasizes cultivation of the learner within an economic framework and, therefore, within the framework of *social*-natural sciences. The functions of tangible public education pertain only indirectly to physical-natural science education and do so more in regard to methods of integrated instruction than to the specializations of physical-natural science. This is because the fact is undeniable that present occupations and present crafts make up principal sources of learner *experience* for cultivation of learner tangible *Personfähigkeit*. It is likely to remain so for the foreseeable future. This was one primary consideration in the discussion of the role of the work-study advisor earlier in chapter 6, pp. 199-201, of this treatise. The distinction between capital skill education and job skill education is in part the distinction of regarding existing occupations and crafts as *materia ex qua* for mobile capital skill cultivation instead of regarding occupations and crafts as *materia circa quam* for job skill training.

The practice of scientific research and the practice of engineering are both peculiar crafts and these crafts are as fit as any others to serve as *materia ex qua* for tangible education. When I said above that science education *fits inside* a new framework for tangible education functions, it is this to which I was referring. In this treatise I make no pretence of providing immediate answers of a tactical nature for teachers' development of instruction *téchne*. The very novelty of recognizing that a new framework is needed also means that a great deal of research and development remains to be started and carried out. The best that I can provide in this treatise is to offer a few observations and suggestions pertinent to early research and development efforts. As I said earlier in this treatise, teachers are the people who will practice a *science* of teaching. This is no more radical an idea than is the idea that engineers are the people who practice a science of engineering. We already accept the latter. It is time we also accepted the former.

2.3.1 The word ***vocation*** used here refers to one's "calling in life," not one's occupation. The first thing to understand about the **lessons of vocation function** (inclusion in the curriculum of lesson-matters pertaining to developing the learner's personal vocational taste) is that it is always the learner alone who Self-determines his own vocation. A father might try to encourage his son to follow him into the family business, but it is the son who decides whether or not he will do so. It is certainly *not* part of the justifiable function of public education to interfere with family influence in this regard. It *is* part of the justifiable function of public education to cultivate the learner's capacity *to wisely choose for himself* when the time to choose comes. Vocational choices are always matters of personal judgments of taste tempered more slightly than one might think by objective factors of economics. Furthermore, in a Republic *no one* is granted any civil liberty to compel another person, by means of any kind of coercion, to take up any particular occupation.

In regard to tangible science education, *téchne* for the lessons of vocation function requires a cooperation between what people often call "humanities topics" and science topics. This might perhaps seem to be a surprising statement, but I hope to make the truth of it become clearer in what follows. Because the practice of science is only one possible choice of future occupation open to the learner, it follows that ***aesthetical arts*** (chapter 16) in many ways take a leading role in instruction for lessons of vocation. This requires a somewhat radical rethinking in educology because of a longstanding rift between humanities teaching and science teaching. This rift reflects the silos of specialization institutionalized by higher education from 1880 to around 1910 [Wells (2013), chap. 14, §3]. Overspecialization, institutionalized by higher education in the name of utility at that time, caused historically demonstrated hindrances to Progress in American Society that in many ways outweighs beneficial effects specialization has also undeniably demonstrated. It is important to remember that the silos erected from 1880 to 1910 are merely *logical* divisions of topical matters and in no way reflect any *real* division of knowledge. What was established by a mere convention can also be disestablished by another convention.

Let us begin with a few general observations about the lessons of vocation (LV) function. The first one is that the LV function is based on the axiom that learner judgments of taste are formable through instructional education [Wells (2012), chap. 8, pg. 235]. Furthermore, the specifying concept of tangible public education is provided by the Society's social contract. Combining these two considerations leads to the deduction that the aim of instructional *téchne* for the LV function must be to cultivate learners so that as full citizens of Society they are able to contribute to Order and Progress in their Society insofar as the general welfare of their Society is concerned. This aim is one of the fundamental objectives of government (and public education is part of the judicial branch of government). It was explicitly called out as one of government's six general objectives in the preamble to the Constitution of the United States, viz. *to promote the general welfare*.

Personal vocation is an orientation in and part of the character makeup of an individual as exhibited by themes that seem to be present and characterize how he chooses to spend his life. As such, it is a human factor essentially aesthetical and entirely subjective in human Nature. It pertains to the *value structure*[12] each person *builds for himself* through his own experience because a "calling" generally implies or refers to what an individual seems to value most as he *defines himself* in relationship to the world and/or in his relationship to matters of religious faith. An individual's value structure is a principal determiner of his actions. The collective effects of individual value structures exert overwhelming influence on Society overall. The significance of individuals' value structures to Society is therefore something no Society can dare to take lightly or for granted without putting itself in peril. Santayana correctly noted,

> If we appealed more often to actual feeling, our judgments would be more diverse but they would be more legitimate and instructive. Verbal judgments are often useful instruments of thought, but it is not by them that worth can ultimately be determined.
>
> Values spring from the immediate and inexplicable reactions of vital impulses and from the irrational part of our nature. The rational part is by its essence relative; it leads us from data to conclusions or from parts to wholes; it never furnishes the data with which it works. If any preference or precept were declared to be ultimate and primitive, it would thereby be declared to be irrational, since meditation, inference, and synthesis are the essence of rationality. The ideal of rationality is itself as arbitrary, as much dependent on the needs of a finite organization, as any other ideal. . . . In spite of the verbal propriety of saying that reason demands rationality, what really demands rationality, what makes it a good and indispensible thing and gives it all its authority, is not its own nature, but our need of it

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[12] The Critical *Realerklärung* of value structure is: the practical manifold of rules insofar as this structure is viewed in a context of reflective judgment. A value structure is a practical system of self-organizing transformations, in relationship to which values constitute conditions for the assertion of practical rules.

> both in safe and economical action and in the pleasures of comprehension. . . .
>
> To substitute judgments of fact for judgments of value is a sign of a pedantic and borrowed criticism. If we approach a work of art or nature scientifically, for the sake of its historical connections or proper classification, we do not approach it aesthetically. The discovery of its date or of its author may be otherwise interesting; it only remotely affects our aesthetic appreciation by adding to the direct effect certain associations. If the direct effect were absent, and the object itself uninteresting, the circumstances would be immaterial. . . .
>
> In an opposite direction the same substitution of facts for values makes its appearance whenever the reproduction of fact is made the sole standard of artistic excellence. . . . We learn to value truth more and more as our love and knowledge of nature increase. But fidelity is a merit only because it is in this way a factor in our pleasure. It stands on a level with all other ingredients of effect. When a man raises it to a solitary pre-eminence and becomes incapable of appreciating anything else, he betrays the decay of aesthetic capacity. The scientific habit in him inhibits the artistic. . . .
>
> When we see a striking truth in any imitation, we are therefore delighted, and this kind of pleasure is very legitimate and enters into the best effects of all the representative arts. Truth and realism are therefore aesthetically good but they are not all-sufficient . . . Science is the response to the demand for information, and in it we ask for the whole truth and nothing but the truth. . . . Even the scientific value of truth is not, however, ultimate or absolute. It rests partly on practical, partly on aesthetic interests. As our ideas are gradually brought into conformity with the facts by the painful process of selection . . . we gain vastly in our command of our environment. This is the fundamental value of natural science [Santayana (1896), pp. 14-16].

In this lengthy quote the pertinence of the LV function to science education clearly stands out. The LV function addresses learner judgments of taste, however, and all judgments of taste are essentially autistic (not directly communicable by a person to another person). This is, Critically, how one must interpret Santayana's remark about "inexplicable reactions of vital impulses." The essential nature of reflective judgment is its impetuousness, which the value structure moderates.

It follows from these considerations that an observer's ability to gauge or test for a learner's construction of his value system – and, therefore, to gauge the effectiveness of LV instruction – is severely limited by the autism of judgments of taste. Its observability is and can only be indirect. Its assessment, consequently, cannot be reduced to "testing standards" or gauged by "rubrics and metrics" because these are *an*esthetic measures. What marks in behavior does this leave us with?

We are all familiar with words used to label a person's character in relationship to his value system: personal industry; integrity; justice; prudence; intellectual activity; enterprise; courage[13]. These are all things a person "might not be able to define but knows it when he sees it." They are likewise among what Mill called the "qualities in the citizens individually which conduce most to" Order and Progress in Society [Mill (1861), pp. 13-14]. Personal actions we judge-to-imply-the-presence-of these things are **habitual behaviors** and are judged subjectively by judgments of taste. *Behaviors can be cultivated by instruction* orienting the learner to habits of behavior in accord with Society's value norms. The practical follow-on question is: How can this be done?

To ask this is essentially to ask how a Society's culture is preserved and transmitted from one generation to the next. The Critical explanation of ***culture*** is *the entirety of habits, attitudes, moral customs, folkways, and social presuppositions that are typically expressed by the actions of*

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[13] Many people think courage and cowardice are innate traits of an individual. This is not true. Courage and cowardice are both *learned* behaviors. It is important to not mistake courage for fearlessness. If you are never afraid of anything you are never courageous because there is nothing for you to be courageous about. You are courageous if you fear consequences to you if you do your duty but you do your duty anyway.

the members of a Society and cultivated by its socialization processes. A person might feel it is his "calling" to rule a vast empire of subjects and territory but this sort of "calling" is not one that is compatible with the Idea of Social Contract nor is it compatible with a Republic. Every great Society of which we have historical knowledge had its own strong ties of culture that bound its people together and gave them the inspiration and vigor to meet challenges confronting them. It is an attribute of strong Societies found across the spectrum of mini-Societies from the largest to the smallest. For example, Peters and Waterman found that a key distinguishing difference between 'excellent' companies and 'poorer performing' companies was identifiable as a difference in their corporate cultures supported and maintained, interestingly enough, by *mythology*. Specifically,

> Without exception, the dominance and coherence of culture proved to be an essential quality of the excellent companies. . . . In these companies, people way down the line know what they are supposed to do in most situations because the handful of guiding values is crystal clear. . . . [The] shared values in the excellent companies are clear, in large measure, because the mythology is rich. Everyone at Hewlett Packard knows that he or she is expected to be innovative. Everyone at Proctor & Gamble knows that product quality is a sine qua non. . . . Poorer-performing companies often have strong culture, too, but dysfunctional ones. . . . The excellent companies seem to understand that every man seeks meaning . . .
>
> Some of the riskiest work we do is concerned with altering organization structures. Emotions run wild and almost everyone feels threatened. Why should that be? The answer is that if companies do not have strong notions of themselves, as reflected in their values, stories, myths, and legends, people's only security comes from where they live on the organization chart. Threaten that, and in the absence of some grander corporate purpose, you have threatened the closest thing they have to meaning in their business lives.
>
> So strong is the need for meaning, in fact, that most people will yield a fair degree of latitude or freedom to institutions that give it to them. The excellent companies are marked by very strong cultures, so strong that you either buy into their norms or get out. [Peters & Waterman (1982), pp. 75-77]

Culture was preserved in these companies, in part, by stories and even myths similar in some ways to the myths of heroes in classical Helena without the violence. Peters & Waterman wrote,

> As we worked on research of our excellent companies, we were struck by the dominant use of story, slogan, and legend as people tried to explain the characteristics of their own great institutions. All the companies we interviewed, from Boeing to McDonald's, were quite simply rich tapestries of anecdote, myth, and fairy tale. And we do mean fairy tale. The vast majority of people who tell stories today about T.J. Watson of IBM have never met the man or had direct experience of the original more mundane reality. Two HP engineers in their mid-twenties regaled us with an hour's worth of "Bill and Dave" (Hewlett and Packard) stories. We were subsequently astonished to find that neither had seen, let alone talked to, the founders. These days, people like Watson and A.P. Giannini at Bank of America take on roles of mystic proportions that the real person would have been hard-pressed to fill. Nevertheless, in an organizational sense, these stories, myths, and legends appear to be very important because they convey the organization's shared values or culture. [*ibid*., pg. 75]

I will attest that on my very first day at Hewlett Packard in 1975, I spent nearly half of that day being told "Bill and Dave" stories by my new managers and coworkers. They were all very eager to let me know that I was now part of something very special and anxious that I should realize it. It took very little time for me to assimilate that culture because I saw it in action all around me every day. We weren't great planners or ingenious businessmen, but we were, and remained for many years, the acknowledged premier high technology company on the face of the earth. The corporate culture, which we called The HP Way, was the reason for it[14]. The eventual death of that culture at the hands of Taylorism was also the end of HP as an excellent company.

Through stories, legends and myths, a Society transmits a message to its young: *When you are confronted by challenges, this is how we expect you to behave*. This is nothing else than Society teaching its young lessons of vocation insofar as it pertains to the callings of citizenship and patriotism – without which no nation can endure. Here is where ***literature*** has a primary role in teaching lessons of vocation. Great literature and great poetry both convey exemplars and role models to the young. Persons who have become anesthetic to the values of their Society usually cannot see and will often denigrate the importance of such lessons because they have trained themselves to be unable to see beyond the trivially concrete, to be blind to the safety and security that a Society's culture provides for its citizens, and to exhibit an habitual adult egocentrism in their actions that gives priority to Duties-to-Self and values of self-love that evoke those maxims. Such people developed no personal vocation to *be* a citizen; as a consequence, they have made themselves *entitlement citizens* – citizens by label only – who live without personal commitment of allegiance to the American social contract and the Duties of citizenship allegiance requires.

There are LV-conveying *materia* that can be mined and refined from literature and poetry for every developmental level of learner. Consider, for example, how the children's classic, *The Little Red Hen*, can be used to convey LV object lessons pertaining to cooperation and industry suitable for the very youngest learners. Similarly, Horatio Alger-like "rags to riches" stories, shorn of their *deus ex machina* prop of the rich benefactor, can be put to similar use[15]. There are other fictional characters who can be turned into prototypes for the learner to learn to mimic; Mr. Fezziwig in Dickens' *A Christmas Carol* comes to mind here, although the Dickens' tale rather clearly needs to be suitably re-presented in order to capture and keep a young learner's attention. Great poetry can stimulate a learner's development of maxims of reciprocal Duty through the sheer power of words and images to "grip one by the heart" in the free play of imagination and understanding. Consider for example the following excerpt from Emerson:

> In an age of fops and toys,
> Wanting wisdom, void of right,
> Who shall nerve heroic boys
> To hazard all in Freedom's fight, –
> Break sharply off their jolly games,
> Forsake their comrades gay
> And quit proud homes and youthful dames
> For famine, toil, and fray?
> Yet on the nimble air benign
> Speed nimbler messages
> That waft the breath of grace divine
> To hearts in sloth and ease.
> So nigh is grandeur to our dust,
> So near is God to man,
> When Duty whispers low, *Thou must*,
> The youth replies, *I can*. [Emerson (1863), pp. 294-295]

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[14] Packard (1995) is, so far as I know, the sole surviving written document describing the HP Way. In a similar vein, Watson (1963) describes an IBM culture that could accurately be called "The IBM Way."

[15] With very few exceptions, young people starting out in the workplace have little or no financial resources of their own, and there are few to no written stories to guide them in how successes in civic free enterprise can be achieved or to teach them about the gradual and accumulative nature of this process. Here is one of many cases where we are in need of new educational literature and a new genre of authors. The proper Alger-like lesson is that personal and civic industry combines with that of like individuals to the benefit of them all. No man is an island complete unto himself alone.

Theater and film, no less than literature, are sources of lesson matters for LV instruction. It often happens that these convey lessons of less grand but more frequent matters nestled more closely to the common threads of social life. Examples that come to mind here include the movie *Brian's Song* and, oppositely, the Mr. Twimble character in the musical number *I Play It the Company Way* from the musical *How To Succeed in Business Without Really Trying*.

LV lessons can *not* be based solely on ideals but must also forewarn and forearm the learner that his values *will* be challenged by many common hindrances in life. It is important to vaccinate learners against hypocrisies he will encounter lest these discolor and un-socialize his lessons of vocation. It is because these *are* challenged that such lessons are sorely needed so that the learner learns

> The tree the tempest with a crash of wood
> Throws down in front of us is not to bar
> Our passage to our journey's end for good,
> But just to ask us who we think we are [Frost (1924), pg. 238].

These are, as I said earlier, examples pertaining to the wider framework of LV instruction. In the narrower framework of science instruction, stories and tales in which science is explicitly involved provide matter from which the possibility of a science vocation can be offered to the learners. One example that comes to mind here is provided by Bryson's *A Short History of Nearly Everything*. Not only does this book excellently put on display the kinds of wonders for which science seeks the underlying truths; it also excellently puts on display the hindering factors of egotism and overreliance on authority that have dogged scientific Progress since the beginning of modern science. Biographies of famous scientists likewise provide this sort of *materia in qua*. Lesson material exists; it is found all around us. It remains for teachers to mine, refine, and put it to use in public education.

2.3.2 The second tangible education function is based on the ***axiom of skill development***: *skills of Progress in tangible* Personfähigkeit *are developed by exercises of adaptation performance focusing on scheme-building and scheme-regulating that prepare a learner for Welfare success in life* [Wells (2012), chap. 8, pg. 240]. "Adaptation performance" essentially means "practice makes perfect." Individual Welfare is the window through which a learner recognizes how what he is learning contributes to his own personal Progress. Unless it happens that there is something in his learning experience that is aesthetically attractive to him, a learner will generally not take a personal interest in developing some skill *unless* he recognizes or understands that the skill *personally* benefits *him*. If you have spent much time with college engineering freshmen, I think it is likely you will have heard the question, "When am I ever going to use this?" many times. The question displays the importance of this aspect of educational Self-development. If the learner does not take an interest in developing a skill, he will not develop it and instruction will not have accomplished its purpose. Instruction must *cultivate growth* in learner interests.

The function being discussed here is the ***skills of civil liberty*** function (inclusion in the curriculum of lesson matters developing the learner's sense of self-respect by development and practice of basic skills that he can recognize as being pertinent to his ability to achieve Welfare success in life) [*ibid*., pp. 241-246]. It pertains to cultivating the learner's interests in mastering mobile (portable) skills that will be important for him in achieving Welfare success in life. The sense of *self-respect* is a *value* feeling that can be described as "feeling one's own worth." Acquisition of skills that the learner understands as skills that improve his own tangible *Personfähigkeit* appeals to a learner's sense of self-respect. However, it is also a mission of public instructional education to cultivate learner skills in such a way that the learner learns to bind his own actions to maxims of civic behavior, and this is why the function is called skills of *civil* liberty. This is especially crucial in science education because science can be used for *either* socially just or socially unjust purposes. The public aim of tangible skills education was well-stated by Kant:

> By education the human being must therefore 1) be *disciplined*. To discipline means to seek to prevent animality from harming humanity, both individual and social. Discipline is therefore merely taming wildness.
>
> 2) The human being must be *cultivated*. Culture includes teaching and instruction. It is the procurement of skill. This is possession of a capacity which is sufficient for any arbitrary purpose. It determines no ends at all, but leaves this to the later circumstances.
>
> Some skills are good in all cases, e.g. reading and writing; others only for some purposes, e.g. music, which makes us popular with others. Because of the multitude of purposes, skill becomes, as it were, infinite.
>
> 3) It must be seen to that the human being becomes *prudent* also, suited for human society, popular, and influential. This requires a certain form of culture named *being civilized*. For this are needed manners, good behavior and a certain prudence in virtue of which one is able to use all human beings for one's own final purposes. It conforms to the changeable taste of each age. Thus just a few decades ago ceremonies were still loved in social intercourse.
>
> 4) One must also pay attention to *moralization*. The human being should not merely be skillful for all sorts of purposes, but become of the disposition to choose nothing but good ends. Good ends are those which are of necessity approved by everyone and which can be at the same time ends of everyone. [Kant (1803), 9: 449-450]

When specialized to science, this functional instruction is aimed at cultivating mobile *fungible* skills in problem-solving (pertaining to dead matter objects), in discover*ing*, and in applications. At the same time, the individual must bind himself to maxims of exercising his liberty only in a civic manner, i.e., his liberty to use his skills must be constrained by his *civil* liberty under Society's social contract. This is the grounding condition for *deontologically* ethical practices of science and engineering.

I feel compelled to reinforce the statement that the skills to be cultivated are ***fungible*** skills. This means the learner can put them to personal use *for his own welfare purposes*. Here is where I must criticize one of the well-meant but mistaken emphases of the NGSS. This document calls for the introduction of "space science" and "environmental science" into the science curriculum. Now, I am personally in favor of space science and have been since I was a little boy at the dawn of space exploration. I also think the science of the environment is crucially important; scientific neglect of the environment over the past two centuries has come at a cost for which the bill has now come due. I have managed projects that removed threats to the environment caused by some of my factory's manufacturing processes. The founder of the Environmental Science program at the University of Idaho, Margaret von Braun, is a close personal friend and former colleague of mine. I have participated in NASA funded projects. I have always been an ally of both sciences.

However, both special sciences address topics that are extremely complicated, and I see no chance for K-12 instruction in them to impart real understanding of either to young learners because of this complexity. Neither do I think there is much prospect for K-12 instruction to make future citizens better able to judge and vote on political or funding issues pertinent to either because to do so responsibly requires the voter to understand technical details as well as general methods that have little or no practical possibility of being adequately taught at the K-12 levels of public education. This means voters will *not* be better shielded from misguidance by propaganda put out both by those who support and those who oppose space science or environmental science issues. The NGSS asks too much of public education at the K-12 levels, no matter how well-intended its proposals are. As St. Bernard is alleged to have said, "The road to Hell is paved with good intentions."

The situation is different if young learners are taught *mobile* skills for scientific practices. It is different because by having and using these skills future citizens are likewise able to *think for themselves* and *objectively* evaluate issues rather than be made pawns of skillful propagandists. I know of no technical problems or issues that can be solved by hysteria or blind enthusiasm. I know of no technical problems or issues that cannot potentially be solved by the *civic* practice of science and engineering. Citizenship requires a citizen to understand how these practices work.

Skill in practicing the technical arts is not gained by memorizing abstract ideas. The real world is a complicated place, and solving technical problems is accomplished by using a succession of problem-solving steps. *Learning* how to do this likewise involves an integrated succession of lessons advancing from simplified models of idealized elements to gradually more complex but more complete models that more closely approximate real objects. This tactic has been used with much success for decades in engineering college curricula. There is no known reason this tactic will not work at least equally well for public education at the K-12 levels.

This instructional schema is based on two complementary ideas, one fairly well known and one not very widely known. These are the complementary ideas of *scientific reduction* and *model order reduction* (SR and MOR). The chief problem in solving technical problems is the problem of complexity. SR and MOR are the *methods* that have been developed to successfully manage and solve real technical problems in the real world. As an illustration of what I mean, I can hardly do better than Weinberg did when he described how Newton came up with his law of universal gravitation:

> The solar system . . . does not consist of "several bodies in motion." We now know that there are thousands upon thousands of celestial bodies in our solar system plus other matter not contained in "bodies." Any analysis of planetary motions, however, begins by ignoring most of these bodies. They are said to be "too small" to have a significant effect on the calculations. Although this seems a natural step – so natural that texts on mechanics do not ordinarily mention it – it happens to work only in very special circumstances. . . .
>
> To be more concrete, for 10 bodies we would need $2^{10} = 1024$ equations and for 100,000 bodies about $10^{30,000}$. By "ignoring small masses," then, the number of equations is reduced from perhaps $10^{30,000}$ to approximately 1000. At least it would be possible to write down the equations even if we still could not afford to solve them. . . .
>
> And yet, even having reduced the number of equations to 1000 – by applying deeply buried assumptions – we still may not be able to say we have solved this mechanical system. . . . We need further simplifications. Newton supplied an important one in his Law of Universal Gravitation, which has been called "the greatest generalization achieved by the human mind."
>
> The law states that the force of attraction (F) between two (point) masses was given by the equation:
>
> $$F = \frac{GMm}{r^2}$$
>
> where M is the mass of the first, m the mass of the second, r is the distance between them, and G is a universal constant. From the viewpoint of simplification, this equation says more implicitly than it does explicitly; for it states *no other equation is needed*. It says, for instance, that the force of attraction between two bodies is in no way dependent on the presence of a third body, so that only pairs of bodies need be considered in turn, and then all of their effects may be added up. . . .
>
> In the case of the solar system, pairwise superposition reduces 1000 equations to about

> 45, that being the number of ways 10 things can be taken in pairs. . . . We might be willing to stop [simplifying] at this point, although Newton, perhaps because he did not have the computers we have, went further still.
>
> As it happens, the solar system has one body (the sun) whose mass is much larger than any of the other masses, larger, in fact, than the mass of all the other bodies together. Because of this dominant mass, the pair equations not involving the sun's mass yield forces small enough to be ignored, at least considering the accuracy of the data Newton was trying to explain. (Discrepancies in this assumption led to the discovery of at least one planet that Newton did not know.) This simplification, which is made possible by the solar system rather than by mechanics, reduces the number of equations to about 10, instead of 45 . . .
>
> But Newton went even further than this, for he observed that the dominant mass of the sun enabled him to consider each planet together with the sun as a separate system from each of the others. Such a separation of a system into noninteracting subsystems is an extremely important technique known to all developed sciences . . .
>
> At this point, Newton stopped simplifying and solved the equations analytically. He had actually made numerous other simplifications, such as his consideration of each of the solar masses as point masses. In each of these cases, he and his contemporaries were generally much more aware of – and concerned about – the simplifying assumptions than are many present-day physics professors who lecture about Newton's calculations. Students, consequently, find it hard to understand why Newton's calculation of planetary orbits is ranked as one of the highest achievements of the human mind. [Weinberg (1975), pp. 4-12]

Contained in this one example are many of the most important techniques of SR and MOR. Scientific reduction essentially consists of separating out the "noninteracting subsystems" of a complex system (together with any interactions if these subsystems do in fact interact). Model order reduction essentially consists of simplifying the system of equations that approximates the system being analyzed. The overall method can be thought of metaphorically as a "ladder" of scientific reduction and model order reduction. Figure 6 illustrates such a ladder in the context of neuroscience. A more extended discussion of all this is provided in Wells (2011).

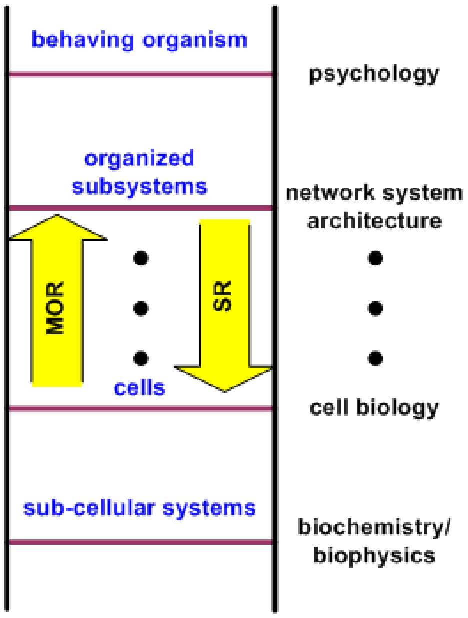

Figure 6: Illustration of the ladder metaphor for scientific reduction (SR) and model order reduction (MOR) in the context of neuroscience. Special disciplines are represented as "rungs" of the ladder. Rungs do not "float." System theory adds the "rails" of the ladder that hold the "rungs" in place.

Continuing the metaphor, specialists work on the "rungs of the ladder"; system theorists, on the other hand, specialize in the "rails" of the ladder. Their job is provide structural continuity to science all "up and down" the ladder. For example, a bridge is made of atoms; yet a civil engineer does not design a bridge by thinking about atoms. He has to know a few things about atoms to do his job, but he does not have to know about "quarks" and the equations he uses for bridge design have no trace of atoms *per se* explicitly contained in the objects of these equations. If anyone tried to design a bridge by working exclusively at the level of atoms, the bridge would never be designed at all. The SR-MOR ladder makes *all* the modern technical arts practically possible.

Instruction in the technical arts is most effective when it progresses from the simplest forms of models (kinematics, Newton's laws, Ohm's law, the IA, VIA and VIIA columns of the periodic table and valence formulas, etc.) and progresses toward more complicated (but more realistic) models. As I said earlier, physical nature is complicated and skill in manipulating and understanding it depends on the ability to break it down into simpler constituent parts. An important part of this is instruction in model-*building*. Traditional instruction treats models far too casually. What is usually done is that the learner is *presented* with already known models without giving him any instruction on where these models came from, how they were developed, and when it is and is not appropriate to use them. This can have no other result than to make the simple models objects for memorization instead of pragmatical understanding. No one can competently put science to use by rote memorization. Intentionally *or* unintentionally cultivating *habits* of memorization is an extremely crippling hindrance to the learner's ability to develop mobile skills.

One effective way to teach the process of model-building is by combining 'experiments to see what happens' with exercises in hypothesis-making for the purpose of trying to explain what one has seen. Even in schools where lab experiments are already part of the science curriculum, what is traditionally omitted is follow-up hypothesis-making. Model-building and hypothesis-making are *conjoint* activities in science education. You can't build a model without some hypothesis that the model is intended to represent. You can't make an hypothesis without a model *because any model is a mathematical statement of an hypothesis*. The two activities are co-determining. If the hypothesis-making-and-model-building-process is omitted, memorization becomes the learner's only means of responding to the lessons presented to him – and that is *not* a science education.

Faraday's *Researches* is a first-rate example of this process for teachers (but not for young learners) that can be used as a background resource for both teacher education and educational Self-development activities engaged in by teachers. It can, however, only serve as an educational example because the scope of Faraday's work is restricted to the topics of electricity and magnetism. "Faraday-like" programs of successive lessons will have to be designed and tested for each of the divers scientific topics. Part of this must include the development of age-appropriate laboratory manuals for the learners to use. This is an important task for education research.

Two challenges attend all this. First, the simplest models are highly idealized and, for that reason, are not very representative of actual natural experience. The ones found in textbooks are idealized products of scientific reduction. Second, the simplest models represent phenomena that, to put it bluntly, most people think are not very interesting upon first encounter. Consequently, many learners find it difficult to conceive of science as having immediate relevance for their own lives. Counteracting this normal reaction falls to the lessons of vocation function in tangible education rather than the skills of civil liberty function. In this context, instruction in ***natural history*** (which covers broad, sweeping accomplishments in science and engineering) is more appropriate for the youngest learners. Effective instruction in natural history exposes learners to the *Dasein* of many wondrous natural phenomena. A "Watch Mr. Wizard" introduction can be made to cultivate the much higher level of personal interest required for competent study of ***natural science***. Even the environmental and space sciences can be treated as natural history until later middle school and high school levels of public education, although no one should think that this is skill preparation for these topics as natural sciences. In this vein, Durant made a remark worth noting:

> Magic begins in superstition and ends in science. . . . Frazer has shown, with the exaggeration natural to a brilliant innovator, that the glories of science have their root in the absurdities of magic. For since magic often failed, it became of advantage to the magician to discover natural operations by which he might help supernatural forces to produce the desired event. Slowly the natural means came to predominate, even though the magician, to preserve his standing with the people, concealed these natural means as well as he could, and gave the credit to supernatural magic – much as our own people often credit natural cures to magical prescriptions and pills. In this way magic gave birth to the physician, the chemist, the metallurgist, and the astronomer. [Durant (1935), pp. 67-68]

Modeling in natural science and design engineering is procedurally similar in a number of ways to techniques of structured computer programming, particularly in regard to functional definition and hierarchy of procedure-subprocedures layers. This is because a computer program is an expression of mathematics. Indeed, a computer program that simulates a natural system is nothing else than a mathematical description of that system's model. Consequently, exercises in writing computer programs can be made to complement exercises in natural system modeling and *vice versa*. Examples of this are provided in Yi (1999) and Yi (2002).

Finally, I want to reemphasize that the existing sciences are just examples, sources of *materia ex qua* for science instruction. The aim of science instruction in public education is not job skill training for future scientists in the existing fields of science. It is *to build scientists*, i.e., people who have acquired mobile skills of technical art *by means of which* ***any*** *craft might be turned into a science*. In 1860 there was no science of electrical engineering; imagine what life would be like today if no one had ever developed that science. Luddites might prefer it, but few of the rest of us would. In 1921 there was no science of space exploration, hence no science of artificial satellites. Our global communications system would not exist if no one had ever developed satellite science. In 1942 there was no computer science. The computers you rely upon so heavily today would not exist if no one had ever developed computer science. In 1947 there was no science of information theory. The streaming video you might have watched today would not exist if no one had ever developed this science. Success in individual entrepreneurship and freedom to enterprise depends on individuals' abilities to develop new technical arts, and it has been this way ever since some unsung hunter-gatherers of lost antiquity developed professional bow-making. The tangible economic world is not a static environment and we must stop teaching science as if it were.

§ 2.4 The Persuasion Education Functions

The two functions of persuasion education are strongly interlinked in science instruction. The functions are the ***heuristics of experimental learning function*** (inclusion in the curriculum of lessons and exercises in experimental learning for how to discover possibilities and options through the use of heuristics) and the ***ends and means planning function*** (inclusion in the curriculum of lessons and exercises evoking Progress in the learner's ability to synthesize and identify objective ends he intends to achieve and objective means of achieving them) [Wells (2012), chap. 9, pp. 265-269]. At first glance one might well wonder why these functions are called persuasion functions since their names might seem to have nothing to do with persuasion. To better understand this, first note that these functions are functions in the personal dimension of the learner. Second, note that before a person can attempt to communicate his ideas and persuade others to accept them, that person *must first persuade himself* of their veracity. (I am, of course, speaking of honest persuasion rather than persuasions of propaganda and other methods of deception). It is true enough that persuading oneself of one's own ideas isn't very difficult but the education issue includes *not* persuading yourself to believe something that isn't true.

The instructional character of these functions is perhaps most clearly conveyed by the axioms from which the functions were deduced [*ibid*., pp. 257-258]. The experimental learning function is deduced from the ***axiom of procedures*** (the learner's capacity for problem solving and decision making is limited by the sphere of his concepts of procedural schemata that he has built up in his manifold of concepts). In the context of science instruction, the function and the axiom pertain to a person's *ability to hypothesize*. I am not speaking here of the raw ability to make a guess (in the connotation of the word 'hypothesis' as 'a scientific guess based on facts'). It requires no special instruction for a human being to learn to guess. I am instead speaking of the ability to use guesswork efficaciously and systematically in *scientific thinking*.

Many scientists seem to be reluctant to admit to the public that *all* new scientific theories begin with guesswork. Some seem reluctant to admit this to themselves. I am not speaking here of the relatively trivial logical deductions that follow as consequences of making a premise. Rather, I am speaking of coming up with premises because scientifically significant discovery is always discovery of a scientific premise that has demonstrable agreement with the sum total of known and relevant real experience. Physicist and Nobel Laureate Richard Feynman said,

> In general we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of this computation to nature, with experiment or experience, compare it directly with observation, to see if it works. [Feynman (1965), pg. 156]

Feynman does not mean to imply that a scientist sits around making random guesses and then checking them out. There is always some body of experienced objective facts that make up the basis of scientific searches for causative explanations or problem solutions. Scientific guesswork (hypothesizing) always begins with these. In physics, for example, Feynman tells us,

> [The statement above] will give you a somewhat wrong impression of science. It suggests that we keep on guessing possibilities and comparing them with experiment, and this is to put experiment into a rather weak position. In fact experimentalists have a certain individual character. They like to do experiments even if nobody has guessed yet, and they very often do their experiments in a region in which people know the theorist has not made any guesses. . . . In this way experiment can produce unexpected results, and that starts us guessing again. [*ibid*., pg. 157]

Scientific inquiry is called "open-minded inquiry" when it begins with raw fact finding and only afterward poses *as many possible candidates* for explanation ('candidate hypotheses') as the inquirer can think up or find. *All* of what is called open-minded *basic* research is characterized by this. *Applied* research differs only in that, between some currently-accepted general premise and the specific facts of some particular special case, there are specific unknowns lying between the general premise and candidate applications for that premise. It happens not-infrequently in applied research that a premise thought to be generally applicable is discovered to in fact be a special case – that an assumption was made in positing the starting premise and that assumption does not hold for the special case. The research must then "search backwards" along the trail of the premise to discover where it had become specialized. The researcher then changes the assumption and proceeds forward again along a *new* deductive path. Indeed, this is characteristic of the majority of all research theses and dissertations produced by graduate students in science, almost all of which are cases of applied rather than basic research projects[16].

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[16] I think it likely Kuhn might have said this is a natural consequence of the use of paradigms in science

This disciplined methodology – that of posing multiple candidate hypotheses for known and verifiable facts – is central to open-minded scientific thinking. By means of it scientific progress is quickened. This is because the weakness of posing only one hypothesis is that a scientist is a human being and is as prone to "seeing what he expects to see" (satisficing by means of type-α compensations) as any other human being. In extreme cases, it also fosters crackpot speculations. *Discipline* in the practice of science is a *learned and habituated* behavior.

Although this chapter is about science education, I do not exclude the application of scientific thinking to problem solving in business, management or any other field. Hypothesizing is, indeed, one of the essential steps for what is known in management training as Kepner-Tregoe (KT) analysis. Perrin Stryker wrote,

> [The] cost of unsystematic and irrational thinking by managers is undeniably enormous. If he wants to, any good manager can easily recall from his experience a wide assortment of bungled problems and erroneous decisions. As an executive of a large corporation long honored for its good management once said to me, "The number of undisclosed $10,000 mistakes made in this company every day makes me shudder." However, like others in management, this executive did not think his subordinates could be trained to think more clearly about problems and decisions; he remained inarticulate about his own thought processes and did not seriously question his habits and methods in handling problems and making decisions. [Kepner & Tregoe (1965), pg. 1]

Kepner & Tregoe (1965) goes on to demonstrate that such training *is* possible and habits of unsystematic thinking can be broken and replaced with systematic ones. The experimental learning function is educationally applicable to all manners of exercising all kinds of technical arts.

An example *par excellence* of a person who skillfully employed hypothesis-making is Piaget. Piaget did not start forming hypotheses until *after* he and his coworkers had gathered many facts of observation. *Then* he would gather as many supportable hypotheses as he could find prior to examining them, one by one, with the deductive process.[17] Indeed, a case could be made that Kepner and Tregoe merely rediscovered, and skillfully articulated, a thought process great scientists had been using since the days of Newton. Piaget's scientific work habits were strikingly different from the work habits of many American psychologists. He once said,

> [The empiricists] talk all the time about Piaget's "system." I've never had a system. I put successive things together after the fact. I always face the unknown with a new problem and attach the results to those we've already found. Well, of course, that makes a system, but it isn't pre-established with regard to new research. Far from it. [Bringuier (1977), pg. 143]

The discipline of open-minded hypothesizing has been called for as a *necessary* discipline since the dawn of modern science. Lack of it contributed to stagnation in Scholasticism. Bacon wrote,

> Nor can we suffer the understanding to jump and fly from particulars to remote and most general axioms . . . and thus prove and make out their intermediate axioms according to the supposed unshaken truth of the former. This, however, has always been done to the present

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[Kuhn (1970)]. If he wouldn't have said it, I nonetheless will.

[17] One of my most cherished teaching moments came a number of years ago when one of my graduate students walked into my office with a dismayed and dejected look on his face. "I have bad news," he said. "I got the data back this morning." The reason he thought it was bad news was because the data strongly disagreed with his theoretical model. I chuckled briefly and asked him, "How can data be bad? Data tells us what is true." He had become fixated on one hypothetical premise, which proved to not be true in his case. He corrected this and went on in the following months to make a very original and important discovery.

> time . . . But we can only auger well for the sciences when the ascent shall proceed by a true scale and successive steps, without interruption or breach, from particulars to the lesser axioms, then to the intermediate (rising one above the other), and lastly to the most general. For the lowest axioms differ but little from bare experiment; the highest and most general (as they are esteemed at present) are notional, abstract, and of no real weight. The intermediate are true, solid, full of life, and upon them depend the business and fortune of mankind . . . We must not, then, add wings, but rather lead and ballast to the understanding to prevent its jumping or flying [Bacon (1620), pp. 82-83].

The most fatal error in the NGSS plan is that, by treating so-called "disciplinary core ideas" as axiomatic, it proposes to teach doing science precisely as it was done before Bacon turned it in its modern direction. Its "disciplinary core ideas" are nothing of the sort. They are the equivalent of Bacon's "most general axioms." The plan proposes a strategy of instruction that can only throw science education backwards by 400 years. In this context, the NGSS plan is not seen as "next generation" science at all. It is nothing else than the medieval schoolmen's science of the Middle Ages dressed in a coat and tie instead of an academic cap and gown.

It is all too easy for a person to persuade himself of something that isn't true. Feynman spoke of this in describing what he called 'cargo cult' science:

> [There] is *one* feature I notice that is generally missing in cargo cult science. That is the idea that we all hope you have learned in studying science in school – we never explicitly say what this is, but just hope that you catch on by all the examples of scientific investigation. It is interesting, therefore, to bring it out now and speak of it explicitly. It's a kind of scientific integrity, a principle of scientific thought that corresponds to a kind of utter honesty – a kind of leaning over backwards. For example, if you're doing an experiment, you should report everything that you think might make it invalid – not only what you think is right about it: other causes that could possibly explain your results; and things you thought of that you've eliminated by some other experiment and how they worked – to make sure the other fellow can tell they have been eliminated.
>
> Details that could throw doubt on your interpretation must be given, if you know them. You must do the best you can – if you know anything at all wrong or possibly wrong – to explain it. If you make a theory, for example, and advertise it or put it out, then you must also put down all the facts that disagree with it, as well as those that agree with it. There is also a more subtle problem. When you have put a lot of ideas together to make an elaborate theory, you want to make sure, when explaining what it fits, that those things it fits are not just the things that gave you the idea for the theory but that the finished theory makes something else come out right in addition. . . .
>
> We have learned a lot from experience about how to handle some of the ways we fool ourselves. . . . But this long history of learning how to not fool ourselves – of having utter scientific integrity – is, I'm sorry to say, something that we haven't specifically included in any particular course that I know of. . . . The first principle is not to fool yourself – and you are the easiest person to fool. So you have to be very careful about that. [Feynman (1974), pp. 311-313]

Disciplined hypothesizing is one of the most important safeguards for not fooling yourself.

In order for a person to properly hypothesize in open-minded inquiry, he must gather or generate more than one option for positing potential explanations or solutions. Psychologically, what this means is that he must be able to conceive possibilities [Piaget (1981)]. It takes several years before a child's mental development is advanced enough to do this. As long as a person thinks he has only one option, he has not differentiated actuality from possibility; consequently, that one option is for him what Piaget called a pseudo-necessity.

Children do develop the ability to conceive possibilities and do so without being taught. This is indeed an excuse used for why "brainstorming" or other popular or once popular techniques for conceiving possibilities are not taught in public schools. The ability is taken for granted and it is presumed its instruction is unnecessary. However, this presumption is incorrect. If it was correct, the divers 'self help' guides, e.g. Adams (1979), and company training courses that exist for trying to teach people to "be more innovative" or "think outside the box" would find no market. It is one thing to conceive different possibilities and thereby conceive different options. It is entirely another thing *to make a habit of understanding* that (*i*) divers possibilities can always be found to posit solutions to problems or conceive explanations; and (*ii*) *most* possible causes or explanations are not going to be *correct* causes or explanations. "It *could* have happened this way" is not an objectively valid explanation in science; it is only a speculation.

Specialized technical training quite often has the effect of developing closed-minded habits of thinking. James called this phenomenon "the ways of the shop" [James (1890), vol. I, pp. 121-122]. I have witnessed this many times in my career and seen otherwise capable scientists latch on to a single possibility and waste millions of company dollars prematurely pursuing it. Indeed, *Taylorism encourages this behavior*. "The ways of the shop" is a singularly apt phrase when one considers that from the days of trade apprenticeship until modern times, training in the technical arts almost always consists of "*this* is the way it is done" types of lessons. If one teaches learners from the time they are young until their schooling ends that there is just one way to do something, it is hardly surprising that as adults they become locked into the ways of the shop and the habit of looking for divers possibilities and options remains undeveloped. Science education does the same thing when teachers leave learners with the impression that the currently accepted laws of science are timeless Truths rather than the contingent explanations-as-we-know-them-now that they really are. Very few science curricula provide students with background in the history of that science – a history that inevitably shows that new findings led to new empirical laws and what Kuhn called "scientific revolutions." The theories of empirical science are never *certain*; they are theories established by the criterion of being *beyond <u>currently</u> reasonable doubt*. Feynman said,

> [The] philosophy or ideas around a theory may change enormously when there are very tiny changes in the theory. For instance, Newton's ideas about space and time agreed with experiment very well, but in order to get the correct motion of the orbit of Mercury, which was a tiny, tiny difference, the difference in the character of the theory needed was enormous. The reason is that Newton's laws were so simple and so perfect and they produced quite definite results. In order to get something that would produce a slightly different result [the theory] had to be completely different. In stating a new law you cannot make imperfections on a perfect thing; you have to have another perfect thing. So the differences in philosophical ideas between Newton's and Einstein's theories of gravitation are enormous. [Feynman (1965), pp. 168-169]

Science's fossil museum of extinct ideas includes phlogiston chemistry, caloric thermodynamics, vital *anima* in biology[18], the luminiferous ether in electromagnetics, Bohr's model of the atom, and many other ideas once generally accepted as correct scientific explanations.

William James seems to have been a disciple of the You-Can't-Teach-An-Old-Dog-New-Tricks school of thought. He speculated that there was a "critical time" in which new topical learning took place and, moreover, *had* to take place if it was to take place at all. His specific speculation lacks objective validity and is gainsaid by other observations, but the observations that suggested it to him are worth noting, as are the exceptions he also noted. James wrote,

> In each of us a saturation-point is soon reached . . . the impetus of our purely intellectual

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[18] Harvey (1651), pp. 432-433. The doctrine of vital *anima* was overthrown by Claude Bernard.

> zeal expires, and unless the topic be one associated with some urgent personal need that keeps our wits constantly whetted about it, we settle into an equilibrium, and live on what we learned when our interest was fresh and instinctive, without adding to the store. Outside of their own business, the ideas gained by men before they are twenty-five are practically the only ideas they shall have in their lives. They cannot get anything new. Disinterested curiosity is past, the mental grooves and channels set, the power of assimilation gone. If by chance we ever do learn anything about some entirely new topic we are afflicted with a strange sense of insecurity, and we fear to advance a resolute opinion. But with things learned in the plastic days of instinctive curiosity we never lose entirely our sense of being at home. There remains a kinship, a sentiment of intimate acquaintance, which, even when we know we have failed to keep abreast of the subject, flatters us with a sense of power over it, and makes us feel not altogether out of the pale. [James (1890), vol. II, pp. 401-402]

By this account, we must conclude there are no scientists or, at least, no new ideas in science hatched by people over age twenty-five – in which case we are left to wonder where and when James got his own ideas. (James was forty-eight when *Principles of Psychology* was published). I leave it to you to pick out the explicit self-contradictions contained in his paragraph. (Hint: there are three of them). James was wrong about the you-can't-teach-an-old-man-new-ideas thesis. It is readily observed that older people appear to be more resistant to new ideas and new approaches than young people if they have never acquired a habit and taste for open-minded inquiry. But *difficulty* in learning something new – which is a provocation for type-α compensation – is not the same thing as *impossibility* in learning something new. Cultivating habits of open-minded thinking by cultivating maxims of thinking for conceiving options and possibilities is the object of the heuristics of experimental learning function.

The ends and means planning function is closely related to this. Its cultivation is intimately dependent upon cultivated experimental learning skills and habits, and the planning activities it involves feed back into and reciprocally co-determine the former. The planning function is deduced from the ***axiom of good means*** (the learner will always seek means he holds-to-be good means) [Wells (2012), chap. 9, pg. 257]. However, holding-to-be-good is *always* determined by the process of practical judgment and this process judges actions to be good *solely* by a condition of their non-contradiction of the manifold of rules. It is, if you will, a *negative* judging that is more accurately described as a judgment of "not-bad" rather than a judgment of "good." Actions that led to successful equilibration in past experience are "not-bad" whereas ones that failed to lead to successful equilibration are "not-good." A "not-bad" means *can* become a "not-good" one.

What a person privately holds-to-be a good means might or might not accord with social norms of good behavior. Some *tolerated* social norms can even be antisocial; the ongoing well-being of a Republic requires antisocial norms be reformed. Scientific findings are particularly easy to pervert into deceptive propaganda merely by omitting pertinent facts and enticing the listener to draw false conclusions. Feynman liked to bring out examples of this:

> In summary, the idea is to try to give *all* of the information to help others to judge the value of your contribution, not just the information that leads to judgment in one particular direction or another.
>
> The easiest way to explain this idea is to contrast it, for example, with advertising. Last night I heard that Wesson oil doesn't soak through food. Well, that's true. It's not dishonest; but the thing I'm talking about is not just a matter of not being dishonest, it's a matter of scientific integrity, which is another level. The fact that should be added to that advertising statement is that *no* oils soak through food if operated at a certain temperature. If operated at another temperature they *all* will – including Wesson oil. So it's the implication which has been conveyed [that lacks integrity], not the fact (which is true), and the difference is what we have to deal with. [Feynman (1974), pg. 312]

Product advertising is often propaganda employing deceptions of this sort. Yet this is by and large tolerated in American Society. Why this is so can be can be called one of our great social mysteries. Sometimes advertisements deliberately lampoon the practice; these are *civic* advertisements. However, it isn't product advertisement alone that stands accused of this sort of misconduct. Political factions and "scientists with a cause" engage in it through deceptive uses of statistics. Huff presented example after example of tactics by which this is carried out every day:

> Averages and relationships and trends and graphs are not always what they seem. There may be more in them than meets the eye, and there may be a good deal less.
>
> The secret language of statistics, so appealing in a fact-minded culture, is employed to sensationalize, inflate, confuse, and oversimplify. Statistical methods and statistical terms are necessary in reporting the mass data of social and economic trends, business conditions, "opinion" polls, the census. But without writers who use the words with honesty and understanding and readers who know what they mean, the result can only be semantic nonsense.
>
> . . . This book is a sort of primer in ways to use statistics to deceive. It may seem altogether too much like a manual for swindlers. Perhaps I can justify it in the manner of a retired burglar whose published reminiscences amounted to a graduate course in how to pick a lock and muffle a footfall: The crooks already know these tricks; honest men must learn them in self-defense. [Huff (1954), pp. 8-9]

Education cannot guarantee unscrupulous people will not use statistics to deceive. But it can and must arm every citizen with knowledge of how to detect such attempts, and it must arm scientists with the tools by which they can learn how to ascertain the degree of confidence that can be had in their conclusions. Instruction in elementary statistics and statistical analysis is wholly lacking in American K-12 public school education. The consequence is that the great majority of Americans are almost wholly ignorant of statistics. There is hardly a single aspect of everyday life in a modern Society that is not affected by this ignorance. Speaking more narrowly, good ends and means planning in scientific thinking must include training in how to use and understand statistical analysis in order to ascertain the veracity of conclusions reached. This is an essential part of ends and means planning function instruction in science education.

The two functions are linked in instruction. Pseudo-necessity due to a want of options tends to reinforce habits of subjective private means and aggravates egocentrism. Egocentric means tend to preserve pseudo-necessities through type-α compensation satisfactions. Ends and means planning serves to improve the likelihood of experimentally producing contradictions that cannot be dealt with by type-α compensation, and thus makes more likely the construction of type-β acts of judgmentation and reasoning. It exercises active searching for options and conceptualizing new possibilities. Both must be cultivated as learner habits of thinking scientifically.

§ 3. Challenges for Teacher Education

Effective reform of science education, as described in this proposal, is a radical reform in the sense that traditional science instruction is: (1) too narrowly focused on existing specialties; and (2) the pedagogy is that of the time before Bacon and contradicts modern scientific practice. There are no "core disciplinary ideas" in science. Science education is the teaching of general methodologies and practices for obtaining objectively valid knowledge and building *new* sciences. A teacher who does not know scientific methodologies and practices cannot teach science, yet few teachers are provided with this training by college of education curricula.

Furthermore, there is a serious lack of suitable textbooks, manuals, and other educational material needed to carry out proper science instruction. References cited in this chapter provide a few seed germs for starting to develop such materials, but a great deal remains to be done before the proposal made here can be successfully implemented.

High school science education has for too long been regarded as preparation for college and, specifically, for college science majors. This is not a wholly inappropriate view inasmuch as new sciences frequently emerge from old ones and there are economic purposes served by training traditional scientists. However, the traditional view is overly restrictive and does not fully serve the *general* nature of science, i.e., that all sciences are technical arts and they do not always emerge from existing sciences. Colleges do not "own" exclusive title to public science education.

Lastly, this chapter has pointed out the need in science instruction for aesthetical instruction to accompany it. The brings us to what I call the aesthetical arts framework in chapter 16.

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