From Modeling Schemata to the Profiling Schema:
Modeling across the Curricula for Profile Shaping Education

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Modeling theory is a research-based pedagogical theory that promotes mediated experiential learning of model-laden theory and inquiry in science education. For over two decades, students have constantly achieved significantly better under modeling instruction than under other forms of instruction, especially in secondary school and university physics courses. Modeling schemata have always been the most critical factor underlying students' success. These schemata are generic tools that students use for systematic construction and deployment of scientific concepts and models. Work has been undertaken in the last four years to extrapolate modeling theory and schemata beyond the boundaries of science. Profile Shaping Education (PSE) has emerged in the process with the profiling schema as a major tool to set and deploy benchmarks or outcomes that need to be accomplished in any educational field, and at any grade level. This chapter discusses how the schema in question emerged in the context of PSE, and shows how it is being deployed in various science and humanities fields to organize course materials and conduct various forms of authentic assessment. Data are presented and discussed from the deployment of the profiling schema in the development of the International Arab Baccalaureate.

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Research has been undertaken for the last four years, in part under the auspices of Educational Research Center, to extrapolate the work on modeling theory in science education (Halloun, 1984, 1994, 1996, 1998a & b, 2000, 2001, 2004a & b, 2004/2006, 2007a & b, 2008) into the broader field of education. Profile Shaping Education (PSE) has emerged in the process as a generic educational framework that may be deployed in designing and deploying various curricula. PSE calls for any systemic effort in education to empower the target population (e.g., students, pre-service and in-service teachers, administrators) to develop a particular profile following well-established pedagogic principles and rules (or general and operational standards), and in accordance with well-defined cognitive, metaphysical and educational tenets. The target profile can be readily translated, using a particular profiling schema, into measurable outcomes which would be reified in various course materials, and ascertained in various forms of assessment. This chapter discusses, in the context of PSE, the development of the profiling schema in question, beginning with its origins in modeling theory, and its implementation in certain educational programs, especially the International Arab Baccalaureate (IAB).

Modeling Theory in Science Education

The work of this author on modeling began in physics as part of his PhD dissertation at Arizona State University (Halloun, 1984). Through classroom-based research, scientific models and modeling were originally transposed from professional tools and methodology of scientific research into pedagogical tools and methodology for learning physics meaningfully at the college level (Halloun, 1984; Halloun & Hestenes, 1987). Subsequently, and as an integral part of this author's drive for a "modeling theory in science education", models and modeling gradually evolved into generic pedagogical tools and methodology for meaningful development of any scientific paradigm at any school or university level (Halloun, 2001, 2004/6, 2007a). Unless otherwise specified, any mention in the following of "models", "modeling" and "modeling theory" refers to this author's perspective on these matters as summarized below and as reflected in his work for the pedagogical theory in question.

Modeling theory calls for any science course to help individual students bring their personal paradigms, often governed by naïve realism as educational research showed in the last three decades, into a state of relative *commensurability* with scientific paradigms. A paradigm consists, for us, of major *tenets* (i.e., metaphysical or foundational statements, often of axiomatic nature), *principles* and *rules* that govern development and deployment of certain *habits of mind* (cognitive processes and dispositions) and *episteme* (a body of conceptions or conceptual knowledge). A scientific paradigm is a paradigm accepted and shared by a community of scientists. The corresponding episteme consists of a corroborated scientific theory or set of interrelated theories, with each theory primarily consisting of a set of scientific models and appropriate principles and rules for model construction and deployment. A *scientific model is a representation of a specific pattern* in the real world, and *modeling involves habits of mind for model construction, corroboration and deployment*. The pattern may be about the structure and/or the behavior of a number of physical systems in the universe. Scientific habits of mind include generic cognitive processes (skills) and dispositions (values, attitudes, and other meta-cognitive controls) which scientists systematically invest in the construction, corroboration and deployment of scientific theory, models included.

Modeling theory calls on teachers to empower students to resolve, explicitly and to the extent that is possible in a given science course, epistemic and cognitive incommensurability between naïve paradigms and corresponding scientific paradigm(s), while mediating construction and deployment of scientific models. When students are guided in this direction in the framework of modeling theory , comparative research shows that they become more effective problem solvers (Taconis, Ferguson-Hessler, & Broekkamp, 2001), and that their overall course achievement becomes significantly better under the prescribed modeling approach than under any other form of instruction, especially traditional instruction of lecture and demonstration (Hake, 1998; Halloun, 1984, 1994, 1996, 1998a & b, 2000, 2004a, 2007a & b; Halloun & Hestenes, 1987).

The advocated approach owes its relative success to the fact that it focuses on both course content and instructional methodology, without compromising one for the other, and in ways that bring the foundations of scientific paradigms into consonance, even resonance, with the foundations of human cognition. This is achieved, in part, in the manner outlined in the following six sections.

1. ***Paradigmatic perspective***:

Under modeling instruction, students are guided to develop any conception (concept, law, or any other theoretical entity or statement) or habit of mind (process, skill, or disposition about knowing or learning science) from a paradigmatic perspective, and not in an episodic, piecemeal approach. In such perspective, any learning activity is conducted in the context of the big picture defined by the scientific theory that conception and habit are about, and in accordance with epistemological, methodological and axiological tenets associated with the paradigm which the theory belongs to.

Epistemological tenets, to which we subscribe, postulate that there are patterns in scientific knowledge, just like there are patterns in the physical world. In this world, patterns manifest themselves in the structure and behavior of physical systems, but especially in the conservation or change of state of such systems while interacting with each other. Patterns in the scientific realm are best manifested through scientific models, with each model representing a specific pattern in the structure and/or behavior of physical systems, and making part of a particular scientific theory that sets the scope and structure of the model in accordance with well-defined paradigmatic principles and rules.

Methodological and axiological tenets we subscribe to are primarily those that govern model construction and deployment (corroboration included), and that allow students, in the process, to efficiently develop scientific habits of mind, and ingrain them constructively and productively in their individual mental profiles.

Under modeling instruction, students are constantly engaged in the development of scientific models of increasing level of complexity in accordance with the tenets above. Furthermore, a balance is maintained in the process between the epistemic dimension (conceptions) and the cognitive dimension (habits of mind), with special attention to the latter since habits allow meaningful development of conceptions more than the other way around. Special attention is also devoted to reflect the generic aspect of all habits of mind, as well as of some basic conceptions in scientific paradigms, in ways to allow students realize and appreciate cross-disciplinarity among various scientific fields, as well as between those fields and non-scientific fields. As a consequence, students begin to think coherently and efficiently, and learn course materials meaningfully and productively, especially when they are empowered to take advantage of knowledge (conceptions and habits of mind) developed in one course in other courses and in everyday life.

2. ***Critical Thresholds***:

A number of *thresholds* are defined within every scientific theory that set: (a) a paradigmatic hierarchy in the structure of the theory, and especially (b) an efficient cognitive and pedagogical sequence in the scope of any scientific course which the theory is about. The most critical of these thresholds are the “basic threshold” and the “mastery threshold” (Figure 1). The basic threshold is set between the *core* body of knowledge and the *fundamental* body of knowledge.

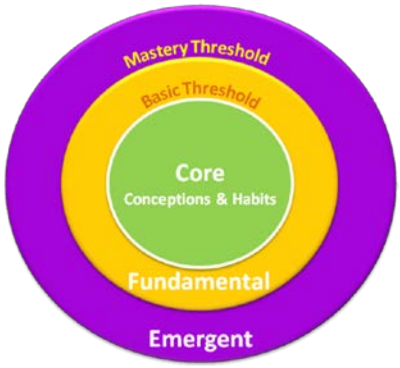

Figure 1: Critical thresholds in the structure of scientific theory, as set from paradigmatic and pedagogic perspectives.

Core knowledge corresponds to a limited number of the most *basic models* in the context of which, from a pedagogical perspective, can be developed the most fundamental and critical conceptions and habits of mind of the corresponding scientific theory. Fundamental knowledge embodies somewhat more complex *basic models* in the context of which students reinforce, and widen the scope of, core conceptions and habits, and derive from them new conceptions and habits. Emergent knowledge typically involves models that may emerge from the composition of two or more basic models, as well as original, more complex models.

A student needs to meaningfully develop the *entire* core knowledge before s/he can proceed to fundamental knowledge. Any flaw in developing any conception or habit of mind in the core knowledge prevents the student from crossing the basic threshold, and thus from developing fundamental knowledge meaningfully. Students normally require significant teacher mediation, in the form described below under modeling instruction, in order to reach such threshold. Once they cross it, teacher mediation can be gradually reduced throughout the fundamental body of knowledge until students cross the mastery threshold. Beyond that threshold, students should be capable of developing the more complex emergent knowledge with the least teacher mediation ever.

For example, in Newtonian theory of mechanics, core knowledge corresponds to the most elementary two *basic particle models* in the context of which students need to develop all basic concepts and laws of Newtonian kinematics and dynamics, as well as basic habits of mind necessary for model construction and deployment. These models are the free particle model representing physical objects in translation with constant velocity under no net force, and the uniformly accelerated particle model representing physical objects in translation with constant acceleration under a net constant force. Fundamental knowledge, in a typical senior secondary school course or freshman college (university) course, involves either or both types of *basic particle models*: bound particle models (circular or simple harmonic motion), and particles interacting with impulsive forces (collision). Emergent knowledge may encompass, in such courses, other types of bound particle models, as well as particle models of objects interacting with velocity-dependent (friction, drag) or time-dependent forces.

Similarly, core knowledge in introductory calculus courses includes three functions (and related differentiation and integration). These are the linear function, $y = ax + b$, the quadratic function, $y = ax^2 + bx + c$, and the linear fractional function, $y = (ax + b)^{-1}$. These functions are *basic* from both mathematical and scientific perspectives. From mathematics perspective, linear and quadratic functions are most foundational. From these two lower order functions emerge other power functions. They are most adequate for students to develop basic aspects of functions, especially rate of change and covariation. In addition, the linear fractional function is important, yet simple enough, for students to develop an understanding of the domain of a function and of asymptotic limits. From science and engineering perspective, the three types of function are simple, yet powerful enough, to allow students to develop basic understanding of how a function allows description or explanation of a given pattern in the structure or behavior of some real-world systems.

As for the basic threshold, it pertains in the case of functions to the process of covariational reasoning about functions in the context of concrete, everyday life situations and other science-related empirical situations. This threshold embraces, among others, cognitive processes required to: (a) tease out primary variables, (b) identify patterns of change (or conservation) in individual variables, (c) coordinate the change of a dependent variable (y) with one independent variable

(x) over a range of values of x (dynamic covariational reasoning about a pattern), instead of associating one value of x at a time with one value of y (localized association game via the input-output machine metaphor), (d) spell out a formal functional relationship between the two variables, (e) use and interpret particular representations of a function, (f) coordinate among distributed representations of the function, and (f) deploy the function in novel contexts.

3. ***Modeling schemata***:

Modeling schemata have always been the most critical factor underlying students' success under the modeling approach. These schemata are generic tools that may be used by teachers for lesson planning and implementation, and by students for systematic construction and deployment of scientific conceptions, especially models. The most important schema originally defined in modeling theory was the model schema.

The *model schema* was originally introduced as a four-dimensional template for putting together any scientific model, at least those models that are the object of study in secondary school and college science. Two of the four dimensions, composition and structure, set the ontology and function of the model, and the other two, domain and organization, set its scope, all in terms of the scientific theory which the model belongs to, and by correspondence to physical realities revealing the modeled pattern.

The *domain* of a scientific model includes all physical systems manifesting the pattern which the model represents. A model's domain is delineated by specifying those systems, as well as the conditions under which the model can represent the pattern in question, and the corresponding limits of approximation and precision.

Model *composition* consists of concepts representing *primary* constituents and respective properties of physical systems, i.e., only those constituents and properties that are salient to the pattern. Explicit focus on model composition is meant to help students discern between primary and secondary aspects of a pattern, i.e. between those aspects that need to be accounted for in the modeling process and those that may be ignored within the considered limits of approximation and precision. In model composition, primary object and property concepts are only listed and not related to one another.

Model *structure* spells out relevant relationships among primary features (constituents and their properties) of the pattern represented by the model. Model structure can be defined along four sub-dimensions, or facets, each dealing with a specific aspect of the pattern. These are the topology facet, the state facet, the interaction facet, and the cause-effect or causal facet. Each facet comes primarily in the form of laws that help setting the distinctive descriptive and/or explanatory *function* of the model. The topology facet specifies what entities the model consists of (e.g., particles or solids in mechanics) and how these entities are positioned in a given reference system. The state facet spells out state laws that *describe* the behavior of each entity (e.g., kinematical equations of motion). The interaction facet consists of interaction laws that govern how various entities interact with each other (e.g., Newton's law of universal gravitation and Hooke's law). The causal facet provides cause-effect laws that *explain* the behavior of each entity (e.g., Newton's second law).

Model *organization* situates a given model in the respective scientific theory. It establishes the potentials and limitations of the model, and relates it to other models in the theory (showing differences and similarities). It also sets rules for extrapolating the model in the construction of new models within and outside the scope of the theory in question.

A similar schema was originally defined for *concept* construction and deployment. As we shall see below, various modeling schemata have evolved recently into a single, generic schema that may be deployed in any educational field and not only in science.

4. ***Progressive middle-out approach***:

Models are at the center of what we call *middle-out* epistemic and cognitive structure of scientific paradigms. They are in the “middle” of conceptual hierarchy, between theory and concept. A scientific model is to theory and concept what an atom is to matter and elementary particles. Each elementary particle is essential in the structure of matter, but its importance cannot be conceived independently of its interaction with other particles inside an atom. It’s the atom and not elementary particles that give us a coherent and meaningful picture of matter, and it’s the atom that displays best the role of each elementary particle in matter structure. As such, models: (a) ensure a cohesive structure of scientific theory, and (b) constitute the most accessible, efficient and reliable building blocks in knowledge construction and deployment. Models subsequently ensure theory and paradigm coherence and consistency from an epistemic perspective, and they facilitate development of scientific knowledge from a cognitive perspective.

Modeling theory calls for the development of any course of science in a middle-out approach from both epistemic and cognitive perspectives. Accordingly, (a) all target conceptions at any level, especially in the core knowledge, are supposed to be developed as building blocks of corresponding models, and not as self-contained entities, and (b) all target habits of mind are meant to be developed in the process, beginning with subsidiary models. A *subsidiary model* is a simplified version of a target scientific model, a particular case which students may usually be most familiar with, and which can serve as a stepping-stone for the comprehensive construction of the target model.

For example, a particle in free fall (objects falling in vacuum in the absence of any force except for gravity) may serve as a subsidiary model of the uniformly accelerated particle model in Newtonian theory. To construct the latter model, students may begin resolving any incommensurability between their own ideas about free fall and the Newtonian perspective on this type of translation. They would then gradually develop this subsidiary model restricted to the case of linear motion in a constant gravitational field, and extrapolate it into the broader case of parabolic, uniformly accelerated motion under any type of a net constant force (or field). The subsidiary model in question would thus serve, at the lower end of the middle-out hierarchy, to develop or refine conceptions and habits required for the particular instance of free fall, and, at the upper end, to extrapolate the subsidiary model into the construction of the target uniformly accelerated particle model. Meanwhile, habits of mind developed, and/or refined, in the context of the subsidiary model, would be gradually de-contextualized in the process, so that students may subsequently deploy them into more complex situations within and outside the context of the course in which they are enrolled.

5. ***Experiential learning cycles***:

Under modeling instruction, students are constantly engaged in a variety of hands-on, minds-on modeling activities that help them develop scientific conceptions meaningfully, and scientific habits of mind productively. All activities are conducted within well-structured learning cycles. A learning cycle is, for us, a modeling cycle, a cycle for model construction and deployment. Each cycle begins with an exploration phase whereby students discover the potentials and limitations of knowledge (models) they have developed so far, and realize the need to construct a new model that represents a specific pattern. Students are then directed to formulate appropriate hypotheses about the desired pattern, i.e., to propose a candidate model, and design and implement an appropriate strategy for testing their hypotheses. The strategy would take them into a process of gradual corroboration and progressive refinement of the proposed model. At certain points during the process and afterwards, students deploy the model in order to consolidate it and relate it to other models within the context of the theory which all these models belong to.

In all activities, students follow an *experiential* approach that involves a variety of *dialectics* within and between two worlds, the *empirical* world of physical realities and related data, and the *rational* world of students' own realm and/or the scientific realm. Students thus develop their epistemic and cognitive knowledge through interaction, or rather transaction in Dewey's sense, with empirical data. This is in contrast with *traded knowledge* that one learns *about*, mostly at face value, and by rote, from other people, from textbooks or any other medium of information dissemination.

Modeling activities are diversified so as to help individual students develop a balanced diversity of habits of mind pertaining to *exploratory* inquiry and *inferential* inquiry, on the one side, and *innovative* research on the other side. Exploratory inquiry may involve description or explanation of existing realities (systems and phenomena), and inferential inquiry may involve prediction or post-diction of the future or past evolution of such realities. Both types of inquiry do not involve any conscious or deliberate interference by the observer in the state of systems under inquiry. Innovative research involves such interference in order to reify a model (a pattern) through control or change of existing realities or through design and construction of new realities.

Appropriate dialectics are prescribed within and between the rational realm and empirical world in all three types of activities in view of helping students resolve any incommensurability between their own paradigms and scientific paradigm(s). Rules of engagement may somewhat recapitulate the historic development of scientific paradigms in the manner discussed below.

6. ***Mediated regulation*:**

Modeling instruction is student-centered, teacher-mediated. It is student-centered in the sense that it engages individual students actively in the learning process, but it does not leave them out entirely on their own free will. Any course has a specific agenda to fulfill: meaningful and insightful paradigmatic evolution within the confinements of a given curriculum. This agenda cannot be fulfilled without teacher mediation that prevents students from going astray and wandering in futile paths, and that keeps their modeling activities aligned as closely as possible with scientific inquiry.

Teacher mediation is meant to constantly induce students to reflect back on whatever epistemic or cognitive knowledge that they might already possess, and that relates to what they are learning in the classroom. Such reflection is made *insightful* in the sense that individual students become consciously aware of the limitations of their own conceptions and habits of mind, and of the sources of error when committed, and they explicitly realize what makes scientific realism superior to naïve realism from all perspectives. The reflection is also *regulatory* in the sense that individual students resolve any incommensurability between their own paradigms and scientific paradigms, and they proceed through a paradigmatic evolution that meaningfully tames down naïve realism in favor of scientific realism.

Educational research has systematically shown in the last three decades that student naïve paradigms are often reminiscent of pre-Galilean paradigms. Teachers are subsequently encouraged to turn to the history of science in order to better understand the foundations of student paradigms and identify historical cases that may be deployed in educational settings for regulating students' knowledge and resolving incommensurability between student paradigms and scientific paradigms. In this respect, student regulation may be directed in ways that recapitulate the history of science, especially at critical turning points whereby Galileo and his successors relied on systematic modeling of physical patterns to overcome the limitations of naïve thinking and take science into major paradigmatic shifts. In fact, student realism is often successfully regulated under modeling instruction to reach certain level of commensurability with scientific realism, by guiding students through processes similar to those of successive refinements of model-laden theory and inquiry which Galileo and his successors went through.

Depending on the level of incommensurability between student paradigms and a given scientific paradigm, and/or the degree of novelty of the latter paradigm (since not every scientific paradigm has necessarily counterpart student paradigms), the intricacy of teacher mediation may go anywhere from providing simple hints to resolve minor inconsistencies, to "lecturing" about a new conception that has no naïve counterpart in students' epistemic repertoire. A trade-off exists between student autonomy and teacher authority in mediated learning. The more students are incapable of regulating their knowledge on their own, the more authority the teacher needs to assume, and the less autonomy students may be afforded, in order to ensure that the target paradigmatic evolution takes place efficiently and within the practical constraints of the course. Teachers can anticipate the type of mediation and level of feedback when they are aware ahead of time of the kind of conceptions students possess about the topic of instruction. To this end, modeling theory comes with a battery of diagnostic instruments (available at *www.halloun.net*), and with means to develop such instruments that would help teachers identify and categorize student pre-instructional knowledge state, and subsequently decide what mediation strategy is appropriate.

Student regulation and thus teacher mediation are not only about the target scientific knowledge. They are also about student learning styles and all meta-cognitive factors that underlie such styles. Teacher mediation is thus also about helping students learn how to learn, i.e., helping them develop appropriate learning habits. Special attention is then paid to attitudes toward science and science education, teacher-student and student-student relationship, confidence, perseverance, and other underlying dispositions. Above all, teacher mediation is conducted so as to help students give up rote learning to satisfy curriculum requirements, and move toward meaningful learning of course materials to regulate their own paradigms. Students are especially directed to take advantage in their everyday life of what they learn in science courses and how they go about learning course materials, and to realize that scientific paradigms, especially scientific habits of mind are viable not only for the development of scientific theory but, most importantly, for any person to conduct oneself in modern life in constructive and productive ways.

Profile Shaping Education

Research was conducted in the last four years to extrapolate the work described above into various educational fields outside the realm of science. A novel educational framework emerged as a consequence that calls for education at any level to empower individual students to develop a particular *profile* that helps them succeed in modern life. The profile may be defined in accordance with the local vision for education and adopted metaphysical, cognitive, and educational tenets, and in fulfillment of a number of social, cultural, economic and higher education requirements. The profile can then be *shaped* or reified in a given curriculum in the form of measurable outcomes that are determined in terms of: (a) the paradigm(s) of the field(s) or discipline(s) which the curriculum is about, and (b) corroborated pedagogical principles (or general educational standards) and rules (or operational standards), all grounded in the aforementioned tenets. The nature and repertoire of outcomes are also affected by, and affect, the nature of the existing educational system as well as teacher profile and professional development. Appropriate programs of study, and corresponding methods and means can subsequently be devised to reify outcomes in formal learning and instruction and ascertain the extent to which outcomes are actually being reified in individual students' profiles (Figure 2).

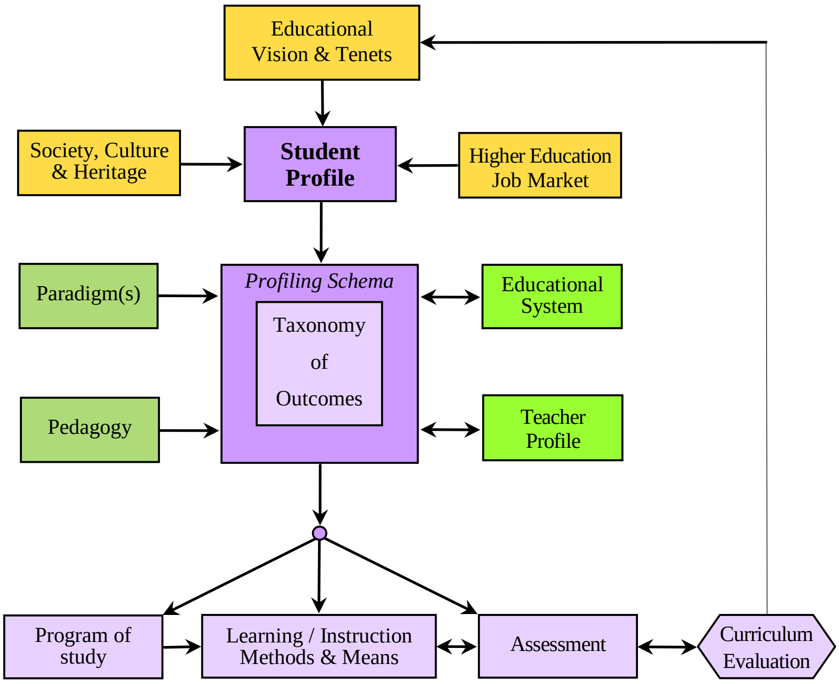

Figure 2: Profile Shaping Education (PSE) curriculum framework.

The Profile Shaping Education (PSE) framework offers a particular 4-P profile as an archetype for secondary school and college curricula. The profile in question is that of a paradigmatic, productive, proactive and principled citizen (Figure 3). Each one of the four p-traits can be translated into appropriate outcomes in a given curriculum in the manner just outlined. PSE provides, for spelling out outcomes, a particular *profiling schema* that has emerged from the modeling schemata in the manner discussed below. Like in the case of modeling theory, PSE calls: (a) for any profile and corresponding outcomes to bring into perspective the *paradigmatic* nature of the field(s) which the curriculum is about, and especially the cross-disciplinary nature of habits of mind and generic conceptions, and (b) for outcomes to be *middle-out* structured in accordance with *critical thresholds* similar to those of modeling theory. In further alignment with the modeling approach, PSE calls on instructors to engage students in well-structured *experiential learning cycles* and *mediate* insightful *regulation* of individual students' profiles so that they become *commensurable* with the target student profile.

Paradigmatic
A paradigmatic student realizes that knowledge construction and deployment in every profession are governed by certain paradigm(s) in line with which s/he needs to develop her/his own profile. For efficient transcendence of personal paradigm(s), the student concentrates on a balanced and comprehensive repertoire of foundational and generic episteme and cross-disciplinary habits of mind that allow her/him to realize the big picture within and across disciplines.

Productive
A productive student relies on systematic ways and means, cognitive and technical, for meaningful development and constructive deployment of conceptions and habits of mind within each discipline, and for productive and creative extrapolation of conceptions and habits into other disciplines and everyday life.

Proactive
A proactive student adopts a clear vision of her/his education and future, and develops an affinity for detecting and resolving problems and for anticipating, and coping with new challenges. The student continuously seeks, and assumes control of, new learning experiences in order to evaluate and regulate her/his own profile; s/he constructively engages with others to help them do the same, and subsequently to empower self and others for lifelong learning and continuous profile development.

Principled
A principled student embraces positive dispositions, especially those that characterize her/his own culture and disciplinary paradigms, and interacts conscientiously, respectfully and constructively with others and the environment.

Figure 3: The 4-p student profile.

The Profiling Schema

Profile Shaping Education (PSE) maintains that the main objective of any curriculum is to reify a particular student profile in the form of outcomes that are commensurate with the professional paradigm(s) covered by the curriculum, and that take into account the cognitive potentials of target students. Curriculum designers have then to spell out an appropriate *taxonomy of measurable epistemic and cognitive outcomes* (i.e., conceptions and habits of mind) for the covered fields or disciplines so that the program of study can be devised accordingly, along with appropriate methods and means of learning, instruction and assessment.

The target student profile is normally defined for a particular school cycle or grade level and not for a particular discipline or curriculum, and so as to concentrate, to the extent that is possible, on generic conceptions and habits of mind that cut across various disciplines and that bring into perspective the big paradigmatic picture within and across disciplines. PSE thus calls for epistemic and cognitive outcomes to be spelled out coherently within a given curriculum, and consistently across various curricula. To this end, it puts at the disposal of curriculum designers, authors and teachers a generic tool which can be used for setting, implementing and assessing the desired taxonomy of outcomes. This tool is the profiling schema.

The *profiling schema* emerged from, and supersedes, modeling schemata. The new schema is an upgrade of its predecessors in two respects, while it preserves significant aspects of the original schemata. First, one particular modeling schema was originally designed for a particular type of conceptions, mainly concepts and models. In contrast, the profiling schema is a generic tool that can be used for spelling out the outcomes associated with any physical or abstract system, and thus with any type of conception. The new schema is underlined by the main metaphysical tenet of modeling theory which asserts that the paradigmatic realm of scientists or any other community of professionals (just like the physical world) consists of coherent conceptual systems, the make-up of which follows specific patterns, and the construction and deployment of which require generic habits of mind. Second, a modeling schema concentrated on epistemic aspects of a given type of conception. Cognitive aspects (habits of mind) were often dealt with outside the context of modeling schemata in modeling theory, and the focus there was on processes required for model construction and deployment. In contrast, the new profiling schema accounts intrinsically for both epistemic and cognitive aspects associated with any system. Like modeling schemata, the profiling schema focuses on features of any system which research, especially modeling research, shows to be comprehensive, from both paradigmatic and pedagogic perspectives, and critical for students at any level to meaningfully understand the system. Those features mainly belong to two dimensions, the scope and structure of any system.

The *scope* dimension specifies the *domain* of a system (what pattern the system represents in either the physical world or conceptual realm) and its *function* (what the system is good for, and under what conditions). The *structure* dimension specifies the *composition* of the system (what primary entities the system consists of, and what are their salient properties), its *internal structure* (how these elements and their properties are related to each other within the system), and its *external structure* (how the system relates to its environment and/or other systems within and outside the confinement of its paradigm).

Figure 4 shows the profiling schema in the form of a template that may be gradually deployed to set the epistemic and cognitive outcomes associated with any system in any educational field, and not only in science. Conceptions and habits of mind may first be stated in general terms (benchmarks) for a given system. As such, the schema serves as a “broad profiling schema”, or “benchmark schema”. Subsequently, or concurrently, conceptions and habits of mind may be translated into measurable outcomes that are suitable for the target population of students. The schema then serves as “outcome schema”.

System: Bohr's Atomic Model		Conceptions	Habits of Mind
Scope	**Domain**	Hydrogen atom and hydrogen-like (or hydrogenic) ions.	Criterial reasoning and discriminative analysis whereby: (a) a pattern is defined among hydrogenic atom/ions that may be classified together and distinguished from many-electrons atoms or ions, and (b) the appropriate theory is chosen to construct and deploy the Bohr model (e.g., the classical theory governing the so-called standard model).
	Function	Description and explanation of certain, but not other, aspects of a single electron bound on a circular orbit.	Logical and critical reasoning by virtue of which particular questions are specified that the Bohr model may answer, to certain limits, about hydrogenic atom/ions, in the context of the chosen theory. Exploratory analysis to set what the model can specifically describe and explain about hydrogenic atom/ions.
Structure	**Composition**	A nucleus with one (hydrogen) proton or more (hydrogenic ions), and a single electron. Properties of interest include mass and charge of these entities, and state properties of the electron (e.g. velocity).	Discriminative analysis by means of which specific (primary) entities (electron and nucleus) and object and state properties are exclusively included in the model, and other (secondary) entities and properties are left out.
	Internal Structure	Interaction between the nucleus and the electron partially represented by a central (binding) Coulomb force exerted by the proton(s) in the nucleus on the electron.	Criterial reasoning to establish either structure, say in the context of classical theory, by analogy to planetary models (e.g., Earth-Moon system in the solar system). Relational reasoning to establish relations between primary properties of various entities in the form of state, interaction and causal laws; and representation dexterity to express those laws algebraically, graphically…
	External Structure	Interaction between the atom in question and other neighboring atoms (molecular structure), or other types of environment (e.g., electromagnetic field).	

Figure 4a: Sample benchmarks associated with Bohr's atomic model in physical sciences.

System: Quadratic Function		Conceptions	Habits of Mind
Scope	**Domain**	An association or a co-variation pattern between an independent variable (argument) and a dependent variable (function value), whereby for every admissible value of the independent variable corresponds only one value of the dependent variable that is proportional to the second power of the value of the independent variable.	Discriminative analysis, along with criterial reasoning, allowing the distinction between functions and other relationships, and the classification of certain functions as quadratic.
	Function	In mathematics, associating two changing objects, or specifying processes that transform one object into another, such that the value of one is proportional to the second power of the other. In science, describing or explaining the state or change of state of a system whereby a given descriptor relates to another proportionally, and to the second power.	Logical and critical reasoning by virtue of which particular questions are specified that the quadratic function may answer, to certain limits, about certain co-variation between two variables and/or the state of certain physical systems. Exploratory analysis to set what the function can specifically tell about the co-variation in question, or describe or explain about the state in question.
Structure	**Composition**	One independent variable or descriptor of specific admissible values (argument, x), one dependent variable or descriptor (function, y), and constant coefficient(s).	Discriminative analysis by means of which specific entities (variables and coefficients) are identified, and others excluded (e.g., non-admissible values of x, variable coefficients).
	Internal Structure	The general algebraic form relating various components is: $y = ax^2 + bx + c$. Graphically, parabola depict quadratic functions. Co-variation between the two variables x and y is further specified with the first and second derivatives (rate of change) of y relative to x.	Relational reasoning to establish the functional relationship between the two variables, along with exploratory analysis to extrapolate to derivatives and integrals. Logical reasoning to infer certain conclusions from symmetry, derivatives, tangents, concavity, etc. Communication dexterity to properly depict various aspects of the function with tables, equations, graphs, and other mathematical representations, and objectively and precisely interpret such depictions.
	External Structure	The factor theorem, and integration and derivation of the function relate it to functions of different power order. In science, this results in certain transformations or in new concepts describing certain rates of change or explaining conservation or change of states.	

Figure 4b: Sample benchmarks associated with the quadratic function (or other power functions) in mathematics.

<table>
<tr><th colspan="2">System:
Greenhouse Model/
Effect (GHE)</th><th>Conceptions</th><th>Habits of Mind</th></tr>
<tr><td rowspan="2">Scope</td><td>Domain</td><td>Atmosphere of earth, or any similar planet affected by global warming.</td><td>Descriptive analysis of the Earth atmosphere and of electromagnetic radiation.</td></tr>
<tr><td>Function</td><td>Description and explanation of global warming.</td><td>Logical and critical reasoning by virtue of which particular questions are specified that the Greenhouse Model may answer, to certain limits, about global warming.
Exploratory analysis to set what the model can specifically describe and explain about global warming.</td></tr>
<tr><td rowspan="3">Structure</td><td>Composition</td><td>Terrestrial globe, infrared radiation, naturally occurring gases in the atmosphere (water vapor, CO2, methane, nitrous oxide & ozone), and human-caused gases (hydrofuoro-carbons, perfluorocarbons, sulfur hexafluoride or SF6).</td><td>Criterial reasoning to classify and quantify various gases and radiations.
Discriminative analysis by means of which specific (primary) entities (gases in the atmosphere and infrared radiation) and object and state properties are exclusively included in the model, and other (secondary) entities and properties are left out.</td></tr>
<tr><td>Internal Structure</td><td>Laws of “optics” describing how infrared “light” can be confined to the Earth atmosphere, and explaining how changes in the atmosphere gases can increase the confinement rate and cause GHE.</td><td rowspan="2">Criterial reasoning to establish either structure by analogy to greenhouses used for farming purposes.
Criterial reasoning, relational reasoning and inferential analysis to quantify various greenhouse processes and statistically analyze their impact on life on Earth. Communication dexterity to take advantage of various mathematical (including statistical) representations in this respect.
Relational and logical reasoning to realize the interaction between human life and atmospheric changes, and appreciate the need to constructively enhance that interaction.</td></tr>
<tr><td>External Structure</td><td>Effect of human activities on earth’s atmosphere, and contribution to GHE (e.g., population growth, farming practices, burning fossil fuels, industrial gases, deforestation).
Impact of GHE on life on Earth.
Necessary changes in people practices, and human adaptation to climate change.</td></tr>
</table>

Figure 4c: Sample benchmarks associated with the greenhouse model/effect in earth science and geography.

<table>
<tr><th colspan="2">System:
Narrative Texts</th><th>Conceptions</th><th>Habits of Mind</th></tr>
<tr><td rowspan="2">Scope</td><td>Domain</td><td>Fiction or non-fiction stories with specific features and generic structure that present a sequence of events according to a specific pattern.</td><td>Criterial reasoning and discriminative analysis to classify various forms of texts.</td></tr>
<tr><td>Function</td><td>Description of a plot in which characters are involved in a conflict, and which evolves in a sequence of events starting with the exposition of the conflict, and ending with its resolution.</td><td>Logical and critical reasoning by virtue of which particular questions are specified that narrative texts may answer about certain stories and plots.</td></tr>
<tr><td rowspan="3">Structure</td><td>Composition</td><td>A plot; major /minor characters; characterization; setting; theme; symbols; point of view.</td><td>Discriminative analysis by means of which specific (primary) entities and properties are exclusively included in the text, and other (secondary) entities and properties are left out.</td></tr>
<tr><td>Internal Structure</td><td>Specification of various components and description of the way they interact and evolve in a sequence of events starting with exposition, rising action, climax, falling action, and resolution.</td><td rowspan="2">Criterial reasoning to ascertain, compare, classify, and contrast to the extent that is necessary characters and settings.
Relational reasoning to relate characters and settings, and thus specify symbols, characterization and theme.
Exploratory and inferential analysis to describe and explain the conflict, and infer a particular ending.
Logical reasoning to set particular assumptions, make metaphors and arguments, and come up with viable points of view, judgments and extrapolations.
Communication dexterity to express all the above with clarity and readily allow sense making and objective interpretation of text</td></tr>
<tr><td>External Structure</td><td>Relation to other forms of texts such as expository texts and argumentative texts.</td></tr>
</table>

Figure 4d: Sample benchmarks associated with argumentative texts in English language.

Figure 4: The profiling schema deployed to set sample benchmarks for specific systems in typical educational fields.

Figure 4 illustrates the use of the schema as a benchmark schema in five educational fields in order to show how generic the schema is, and thus how the tools of modeling theory were efficiently extrapolated across various curricula in the context of PSE. The fields in question are respectively physical sciences, mathematics, earth sciences (and geography), and English language. Each cell in the four instances of the benchmark schema is partially filled with certain, but not all, conceptions or habits of mind that are required in typical systems covered at the secondary school or college level (Figure 4). The reader can easily realize that *epistemic* cells include particular information or theoretical statements about the scope or structure of a given system that are commonly accepted by the concerned community of professionals (scientists, mathematicians or linguists, in the case of our example), and that the student is expected to "*have*" at a given point of instruction. In contrast, the reader can readily realize that *cognitive* cells include what the student is expected to "*be*" capable of doing at that stage, and this in the form of habits of mind, processes or dispositions, which the student is expected to develop in the context of a given system, but which are of generic nature, in the sense that the student can deploy them in the context of any other system.

Cognitive taxonomy

Cognitive outcomes or habits of mind which PSE focuses on to help students develop profiles like the 4-p profile described above (Figure 3) include a blend of processes and dispositions that may be classified in a seven-category taxonomy. The seven categories are listed below along with some of the corresponding habits of mind.

Analysis, which includes exploratory processes allowing the description or explanation (cause identification) of the state or change of state of a given system (or phenomenon) and inferential processes allowing, among others, the prediction (or post-diction) of the state of the system under certain conditions. In all these respects, analysis may be either exhaustive or discriminative. Discriminative analysis is conducted to tease out primary or salient features (entities and their properties) from secondary or irrelevant features, whereas exhaustive analysis results in identifying all features without any distinction.

Criterial reasoning, which includes all sorts of criteria-based judgment and evaluation, like comparison, contrast, classification, analogical reasoning, and pattern recognition, as well as estimation and measurement, all done with special attention to reliability, consistency, objectivity and precision.

Relational reasoning, which includes processes establishing viable (valid and reliable, coherent and consistent) relationships between different features, including syntactical connections, internal or cohesive structure of a system (connecting its features) or its external structure (connecting the system to its environment), correlation, functional relation, synthesis, extrapolation, transfer.

Critical reasoning, which includes processes of reflective thinking, evaluation of claims and evidence, corroboration of claims and hypotheses, question formulation, problem detection and formulation, challenge anticipation, skepticism and questioning "facts", all done with special attention to objectivity and precision.

Logical reasoning, which includes processes of evidence-based argument and corroboration, justification, proof, hypothesis formulation, assumptions making, conjecturing, adduction, induction, deduction, generalization, metaphorical reasoning, esthetical reasoning, insight.

Technical dexterity, which is about efficient and constructive use of computers, ICT media and all sorts of technical devices that are particularly important in education.

Representation dexterity and communication fluency, which include verbal and symbolic expression, graphic and geometric depiction, kinesthetic expression, coordination of various expressions and depictions, semantic processes of interpretation and sense making, all done with eloquence, clarity, objectivity and precision.

It is important to note at this point that there is no particular cognitive hierarchy among the various categories. However, a certain hierarchy may be identified within each category that depends on the variation of complexity of, and cognitive demands imposed by, each habit of mind within a given category. For example, within the category of analysis, we may distinguish between exploratory analysis and inferential analysis. Exploratory analysis is about describing or explaining a particular state of a given system, as it exists at given point of space and time. Inferential analysis is about making inferences about the system in question beyond that particular state, e.g., predicting how the system may evolve in the future under certain conditions, or post-dicting how the system evolved in the past before it got to the state in question. One can readily realize that inferential analysis comes at a higher cognitive level than exploratory analysis, and that explanatory analysis (identifying salient causes of the conservation or change of state of a system) comes at a higher level than descriptive analysis (identifying primary features of a given state).

A particular cognitive hierarchy is defined in PSE that relates to the gradual construction and deployment of a given system along the dimensions defined in the profiling schema (Figure 4). Accordingly, any person may progressively “know” (or “learn” about) a given system, and develop and deploy corresponding conceptions and habits of mind, in four consecutive stages. These are in order:

1. *Initiation* (*primitive learning*), when a learner is simply aware that the system exists, but knows nothing or a little about its scope and structure, and is still incapable of successfully deploying related conceptions and habits of mind in any situation.
2. *Gestation* (*rote learning*), when the learner develops partial knowledge about the scope and structure of the system, and is capable of deploying certain related conceptions and habits of mind, exclusively in the context of the system in question when encountered in familiar situations.
3. *Replication* (*reproductive learning*), when the learner develops satisfactory knowledge about the scope and structure of the system, and is capable of deploying related conceptions and habits of mind, exclusively in the context of the system in question when encountered in familiar situations and new, but mostly similar, situations.
4. *Innovation* (*productive or meaningful learning*), when the learner develops comprehensive knowledge about the scope and structure of the system, and is capable of creatively deploying this knowledge, especially corresponding habits of mind, within the context of the same and other systems encountered in novel, unfamiliar situations.

It is also important to note here that the habits of mind distinguished above are normally gradually developed and deployed not individually but together in various combinations that may be classified in three categories: core-engagement, eco-engagement, and meta-engagement.

Core engagement, which puts together processes and dispositions from all the above categories in the purpose of looking at the big picture of things, designing and carrying out appropriate plans for systemic and system-based thinking (modeling included), experimenting, decision making and problem solving, regulating (controlling or changing) existing situations, crisis management, and ultimately for bringing about creative and innovative ideas and products, and this in scholarly contexts, at school or in the workplace, as well as in everyday life.

Eco- engagement, which includes self-management as well as interaction with others, especially peers (teamwork included), and the environment, all done with integrity, fairness, tolerance, empathy, respect of diversity, open mindedness, while upholding commitment, dedication, perseverance, curiosity, adaptability, and assuming responsibility, accountability, leadership.

Meta-engagement, which includes auditory, visual, and/or kinesthetic assimilation and adaptation of conceptions and various conscious actions for the development of habits of mind, as well as various meta-cognitive controls that govern learning and, especially, learning how to learn.

Deployment

The profiling schema can be used for spelling out, at any educational level, benchmarks and outcomes associated with any profile, and not just student profiles, as well as for many other purposes. In fact, the schema is currently being used at ERC to construct electronic assessment and learning platforms, and to help designing and deploying various curricula, including those for pre-service and in-service teachers. It is also being promoted for tracking the evolution of every learner's profile, so that appropriate learning activities may be designed that help individual learners efficiently develop the target profile, and so as to ascertain whether a given curriculum actually contributes to the development of the profile in question. Like modeling schemata in science education, the profiling schema has begun to prove itself as a significant factor in enhancing the state of things in any educational field.

Our research had long shown that modeling schemata are most critical for the success of the modeling approach (Halloun, 1994, 1996, 1998a, 2003). Cognitive and educational researchers have long argued and shown that scientists are more efficient than ordinary people, including high school and college students, because to a large extent of better knowledge organization as reflected in scientific theory and paradigm. Modeling schemata serve, for both teacher and student, as a tool for epistemic organization. When students are explicitly directed to construct (and deploy) scientific conceptions, especially models, in accordance with these schemata, their understanding of course materials as reflected in course exams and standardized testing reaches significantly higher levels than their peers, including those who follow a modeling approach that does not rely on such schemata (*ibid*).

Research has begun about two years ago on the effectiveness of the profiling schema in various ERC projects. The schema has proven to be instrumental especially in the development of the International Arab Baccalaureate (IAB). IAB is meant to be a common secondary school diploma for the entire Arab World that will, in due course, be internationally recognized. Students are expected to receive the IAB diploma if they develop the profile shown in Figure 3, evidence for which is ascertained through continuous formative and summative assessment of expected outcomes in various fields covered in the three secondary school grades (10, 11, 12). In preparation for its official launch in the coming academic year (2010-2011), IAB has been piloted twice so far, once in May 2009, and another time in March 2010. The first pilot took place in the form of a comprehensive summative exam for grade 12 students in four Arab countries, and the second pilot took place similarly in grades 10, 11 and 12 in the same countries. The first pilot covered physics, mathematics and Arabic language, whereas the second pilot covered physics, chemistry, biology, mathematics, geography, Arabic and a foreign language (English or French). Pilot exams covered outcomes in the mentioned fields that pertain to the profile of Figure 3, and that were determined using the profiling schema illustrated in Figure 4.

A major focus of both pilots was to find out to what extent PSE provides a valid and reliable cross-disciplinary framework for ascertaining the extent to which students develop the target profile (and for ultimately developing the profile). Among others, this meant to ascertain to what extent the profiling schema can be relied upon to set profile-based outcomes for various targeted fields at various grade levels. Last year's data showed that the profiling schema has actually served its purpose in significant ways. For instance, Pearson correlation coefficient among the three exams then administered in grade 12 ranged from .51 ($p = 10^{-20}$), between Arabic and mathematics, to .59 ($p = 10^{-31}$), between mathematics and physics. Closer data analysis revealed that common epistemic and cognitive outcomes laid out in the profiling schema were responsible to a large extent for such high correlation. Data of this year's pilot are still being analyzed, and results will eventually be made available at www.EducationalRC.org/IAB.

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