Interactive Model-Based Education:
An Alternative to Outcomes-Based Education in Physics

Ibrahim A. Halloun

The Lebanese University – P. O. Box 460, Zouk Mekael, Lebanon
Halloun@inco.com.lb

South Africa has recently opted for Outcomes-based Education (OBE) in its primary and secondary school curricula. Interactive model-based education (IME) is an approach for teaching and learning science that is aligned in some respects with OBE, but that differs in others. Major tenets of OBE are first discussed and compared to those of IME. The effectiveness of IME in improving learners' understanding of physics is then shown so as to present it as a viable alternative to OBE.

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Modern trends in education all call for student-centered education with flexible curricula that can be easily adaptable to individual students' competence. The shift from conventional show-and-tell instruction has been called for after many local and international studies have shown that pupils and students at all levels often pass their courses without necessarily understanding the material in these courses. The situation is perhaps most alarming in mathematics and science, and especially in physics (Novak, 1987 & 1994).

The Third International Mathematics and Science Study (TIMSS) has shown that even pupils in developed countries have unsatisfactory understanding of the most elementary conceptions in science and mathematics. About half a million of students enrolled in fifteen thousand schools in forty different countries participated in the 1994 study. South African pupils trailed behind the rest of their peers in mathematics and science (Howie, 1997; *http://wwwcsteep.bc.edu/timss*).

In the last two decades, research in physics education has been constantly showing that conventional physics instruction of lecture and demonstration has no noticeable impact on secondary pupils and college students. Pupils and students often come to their physics courses encumbered with naïve beliefs about the physical world that are incommensurable with scientific theory. They often complete these courses still holding fast to their beliefs, thus misconstruing the scientific message in these courses, whether in relation to the conceptual structure of scientific theory or in relation to its relevance and applicability in the real world (Cobern, 1993; Halloun, 1997; Halloun & Hestenes, 1985 & 1998; Hammer, 1994; Hestenes, Wells & Swackhamer, 1992; McCloskey, 1982; Seepe, 1994; Smit & Finegold, 1995; Smit & Nel, 1997).

Alarmed to this situation, educators in South Africa and in some other countries have sought recourse in *Outcomes-based Education* (OBE), hoping it would be a better alternative to conventional instruction (Ministry of Education, 1997). Other alternatives have been sought in other countries, especially in science and mathematics education. Among these alternatives is what I will refer to in this article as *interactive model-based education* (IME) which, at least in physics, has resulted in significant improvement of student understanding (Clement, 1989; Halloun 1996, 1998; Halloun & Hestenes, 1987; Wells, Hestenes & Swackhamer, 1995; White, 1993; White & Frederiksen, 1990).

In this article, the basic tenets of OBE are first presented and compared to those of IME. Meanwhile, a description is presented from an IME perspective of scientific knowledge that should be targeted in physics education and of the way learners should be guided through to develop such knowledge. The effectiveness of IME in secondary school and college physics is then shown with the implication to opt for IME rather than OBE in science and mathematics education.

OBE and IME: A perspective

The National Department of Education in South Africa (1997a) sees in Outcomes-based Education (OBE) a shift from a teacher-centered, objectives-driven to a learner-centered, outcomes-oriented education; the outcomes being associated with individuals with certain conceptual knowledge and motor abilities. Interactive model-based education (IME) is a name that I give in this article to mainly the type of mathematics and science education that: (a) promotes *active* and *reflective* engagement of learners, and that (b) guides them to *evolve into scientific realism*, chiefly through the *schematic* construction and employment of *conceptual models* of the real world (Halloun 1996 & 1998; Wells et al., 1995).

OBE and IME both stem from modern cognitive theories. OBE is probably most influenced by *constructivism*, whereas IME has benefited from various cognitive theories without bearing the stamp of any one particular school (Halloun, 1998). Furthermore, and unlike OBE, IME is deeply entrenched into the philosophy of science from which it draws its epistemological tenets (Halloun, 1996 & 1998).

Figure 1 shows major differences between conventional (old) instruction and OBE (new) as seen by the South African ministry of education (National Department of Education, 1997b). The nine items in this figure are discussed in the following and compared to what IME holds in their respects. All nine items stem from the general pedagogical tenets of OBE, and some, mainly items 4 and 8, from its epistemological foundations as well. The discussion will be done along the lines of curriculum content or program of learning and instruction (items 4, 6 and 8), methodology (items 1, 3, 5 and 9), and assessment (items 2 and 7).

	Old Approach	**New Approach (OBE)**
1	passive learners	active learners
2	exam-driven	learners are assessed on an on-going basis
3	rote-learning	critical thinking, reasoning, reflection and action
4	syllabus is content-based and broken down into subjects	integration of knowledge; learning relevant and connected to real-life situations
5	textbook/worksheet-bound and teacher centred	learner-centred; teacher is facilitator; teacher constantly uses groupwork and teamwork to consolidate the new approach
6	sees syllabus as rigid and non-negotiable	learning programmes seen as guides that allow teachers to be innovative and creative in designing programmes
7	teachers responsible for learning; motivation dependent on the personality of teacher	learners take responsibility for their learning; pupils motivated by constant feedback and affirmation of their worth
8	emphasis on what the teacher hopes to achieve	emphasis on outcomes – what the learner becomes and understands
9	content placed into rigid time-frames	flexible time-frames allow learners to work at their own pace

Fig. 1. Differences between the “old” and “new” educational approaches in South Africa (National Department of Education, 1997b)

Program

Like OBE, IME denounces the conventional treatment of scholarly knowledge as canned goods that can be delivered to the learners by an authority, be it a teacher or a textbook (item 5 in Fig. 1). However, unlike OBE, IME sets *explicitly*, and ahead of time, the goals or prospective "outcomes" of the educational endeavour, i.e. what it hopes of the learner to "become" and "understand" (item 8 in Fig. 1). This position is taken under IME for at least two reasons:

1. In the absence of clear targets in the head of the teacher, learners would be left to wander in futile and endless labyrinths.
2. Outcomes need to be assessed, and no objective assessment can be made without clearly defined standards to compare the outcomes to.

According to both OBE and IME, the ultimate goal of science education is to empower students with knowledge and skills that are commensurable with those of scientists. However, and because of lack of clear epistemological foundations, OBE does not spell out explicitly the nature, and especially the structure of scientific knowledge that the learners are expected to construct. In contrast, IME holds the position that scientific theory is built around *models* of well-defined structure, and that *modeling* the physical world following well-defined rules constitutes the crux of scientific endeavour. IME thus strives to help learners develop modeling skills and model-centered knowledge.

IME agrees with OBE on the need to allow students develop *coherent* conceptual structures that are explicitly connected to everyday life experience (item 4 in Fig. 1). In conventional science instruction, scientific knowledge is often presented *episodically*. One concept or principle is presented after another without necessarily showing how they all relate to one another in coherent structures. As a result, learners' knowledge about topics discussed in science courses often tends to be weakly structured and fragmented. Furthermore, learners are often led to believe that scientific knowledge, and especially physics, pertains to fictitious situations that have no relevance to everyday life. Consequently, students loose interest in, and motivation about, the educational process (Halloun & Hestenes, 1998).

Dimensions of a model

The *domain* of a model consists of physical systems and phenomena that can be described and/or explained, in some respects, and to a certain degree, using the model.

The *composition* of a model consists of conceptual entities that are grouped in two sets: (a) the set of objects inside the model (content), and (b) the set of agents outside (environment) which interact with the objects inside, as well as of respective properties or descriptors.

The *structure* of a model consists of *relationships* among the descriptors of different entities. Depending on the type of structure included in the model, a model can be descriptive and/or explanatory. Kinematical models of Newtonian mechanics are descriptive, dynamical models are explanatory.

The *organization* of a model refers to its relationship to other models in a given scientific theory. Every theory provides appropriate *classification schemes* for grouping various models into *families* of models, the most fundamental of which are the families of basic models.

A *basic model* is one with simple composition (often consisting of one object) and simple structure (often limited to describing and/or explaining one elementary phenomenon).

Fig. 2. Dimensions that define a model and situate it in a scientific theory.

IME holds the position that the coherence of scientific knowledge is insured by and large by the fact that scientific theory is model-centered, and that learners should thus learn how to construct models of the physical world the way scientists do. IME further assumes that every scientific theory can be built around a few *basic models*, within the context of which learners can develop individual concepts, laws and other constructs (Halloun, 1996 & 1998).

A model is explicitly defined through a set of four dimensions: domain, composition, structure and organization. Composition and structure "define" the model. Domain and structure situate it in the theory to which it belongs (Halloun, 1996). These four dimensions are outlined in Figure 2 and illustrated in Figure 3 with the uniformly accelerated particle model which belongs to the family of basic particle models in Newtonian theory (Fig. 4).

The four dimensions presented in Figure 2 constitute for a model what is often referred to in the literature as *declarative knowledge*. These dimensions are complemented by some *procedural knowledge*. Procedural knowledge consists of the rules that guide the construction and employment of models, and associated with it is a repertoire of familiar situations in which a person had the chance to successfully apply the model (Halloun, 1998).

In conventional instruction, and especially in physics, scientific skills or procedural knowledge that learners are exposed to are often limited to what is required for solving textbook problems. These problems often have no direct bearing to everyday life, and do not require the systematic use of the various aspects of scientific methodology like in the modeling activities described in the following section. Learners often attack these problems by trial-and-error, search for formulas that relate givens to unknowns in a specific problem, or blindly reproduce some solutions presented by the teacher or the textbook that they had already memorized by rote. Learners often succeed by doing so, especially in conventional exams. As a result, learners' procedural knowledge tend to consist of situation-specific recipes memorized by rote and ready to be reproduced only in the short term, and only when called upon through a conventional examination (Halloun & Hestenes, 1985 & 1998).

For meaningful learning of science according to IME, instead of such recipes, learners ought to develop various aspects of *scientific inquiry*. To this end, models and all sorts of constructs should be developed and applied through well-designed activities for *modeling* the physical world. *Paradigm situations* achieve best this goal. A paradigm situation is a situation that requires the comprehensive construction or employment of one or more basic models and that follows a five-stage scheme outlined in Figure 5. Such situations can be encountered in everyday life or the laboratory, or presented in a special type of textbook problems (Halloun, 1996).

Teachers should by no means prescribe such a modeling process passively to the learners; they should guide them to develop it gradually as they go about modeling paradigm situations. To this end, learners should be brought to the habit of asking themselves systematic questions, the answer to which would help them achieve comprehensively and successfully every step of the modeling process (Halloun 1994, 1996).

Uniformly Accelerated Particle Model

1. Domain

All physical systems that are in *translation* with *constant acceleration* in inertial reference systems. Each system is interacting with one or many physical agents that exert on it a net *constant force*.

The model could be kinematical (descriptive, not involving forces), and/or dynamical (explanatory, involving forces), within the framework of Newtonian Theory.

2. Composition

2.a Content: *One* particle representing a system in consideration, and depicted by a geometric point in a coordinate system representing the reference frame.

2.b Environment: Two types of agents are distinguished in Newtonian mechanics, those of interaction at-a-distance (or long-range interaction), and those of contact interaction.

2.c Object descriptors refer to *intrinsic* and *state properties* of the particle-like system. Only one intrinsic property is accounted for in any particle model: the mass of an object. State properties are the kinematical properties of the object. They include position, displacement, velocity, acceleration, kinetic energy, etc. In a coordinate system, state properties are depicted in a *motion map* consisting of a trajectory on which can be shown position, velocity and acceleration vectors at instants of interest.

2.d Interaction descriptors include, among others, the concept of force. Forces exerted on the particle-like system by its agents are often depicted by arrows in a *force diagram*. The net force is evaluated using the superposition principle (Newton's 4th law or law of composition).

3. Structure

3.a Geometric structure, if any in this model, is often restricted to the relative position of the particle-like object and long-range agents.

3.b Interactive structure, expressed by appropriate interaction laws, like the Newtonian law of universal gravitation.

3.c Behavior description: The translation of the particle is described by *motion laws* (state laws) involving only kinematical concepts, such as:

$$\mathbf{a} = \text{constant} \qquad \Delta\mathbf{v} = \mathbf{a}t \qquad \Delta\mathbf{r} = \mathbf{v_o}t + \frac{1}{2}\mathbf{a}t^2 \qquad \Delta\mathbf{v}^2 = 2\mathbf{a}\Delta\mathbf{r}$$

These laws can also be depicted by appropriate *graphs*, *relational diagrams* and/or *motion maps*.

3.d Behavior explanation: Variations of the particle's state properties are explained by *causal laws* such as Newton's 2nd law (dynamical law) or the Work-Energy theorem (conservation law).

4. Organization

Newtonian Theory relates the uniformly accelerated particle model to:

- other models within the family of particle models (Fig. 4).
- rigid body models and other families of models (e.g. fluid models) within the theory.

Consequent rules are established within the theory that tell us how to combine this model with other basic models to study physical systems undergoing more complex motions. For example, this model can be combined with the uniformly circling particle model to describe, explain, and/or predict the behavior of an object that undergoes a circular, uniformly accelerated translation. If the object were also rotated about a specific axis (like in the case of Earth), the *emergent* model thus constructed could be further combined with the appropriate rigid body model.

Fig. 3. The Newtonian uniformly accelerated particle model (Halloun, 1998).

Basic Particle Models

Particle models refer to physical objects the internal structure of which can be ignored when they are in *translation* without rotation or precession, in a specific reference system. The content of each *basic* particle model consists of a single, dimensionless object: a particle. Basic particle models include:

Free Particle

This model refers to physical objects subject to zero net force ($\Sigma\mathbf{F}_i = 0$) in linear translation with constant velocity or at rest.

Uniformly Accelerated Particle

This model refers to physical objects subject to a net constant force ($\Sigma\mathbf{F}_i$ = constant), hence moving with constant acceleration in a linear or parabolic path.

Harmonically Oscillating Particle

This model (often called simple harmonic oscillator) refers to physical objects subject to a net force that is proportional to their displacement from a center of force ($\Sigma\mathbf{F}_i \quad \Delta\mathbf{r}$), hence undergoing simple harmonic motion.

Uniformly Circling Particle

This model refers to physical objects subject to a net centripetal force ($\Sigma_{\text{radial}}\mathbf{F}_i \quad 1/r^2$) of constant magnitude, hence undergoing a uniform circular motion.

Basic Rigid Body Models*

Rigid body models refer to physical objects the internal structure of which cannot be ignored when they are in *translation* and/or *rotation* and/or *precession*. The content of each *basic* rigid body model consists of one solid of a regular geometric shape rotating (precession ignored) about a specific axis (that may be fixed or in translation, and that can be modeled like a particle). Basic rigid body models include:

Freely Rotating Rigid Body

This model refers to physical objects subject to zero net torque about a specific axis ($\Sigma\tau_i = 0$), hence rotating with constant angular velocity about this axis or at rest.

Uniformly Accelerated Rotating Rigid Body

This model refers to physical objects subject to a net constant torque about a specific axis ($\Sigma\tau_i$ = constant), hence rotating with constant angular acceleration about this axis.

Fig. 4. Two families of basic models in Newtonian theory (Halloun, 1996).

* Euler's laws (which are sometimes wrongly referred to as "Newton's laws of rotation") govern the rotation of rigid body models. Euler's laws follow the Newtonian philosophy. In this respect, the family of rigid body models is here considered part of the "Newtonian" theory. One, though, could still refer to "Newtonian Theory" in the narrower sense, and restrict it to particle models.

Modeling paradigm situations

1. ***Model selection.*** Individual systems are first conveniently defined in the situation. Then an appropriate model is adopted to represent each system within the framework of an appropriate scientific theory. The model can be entirely new or chosen from the person's repertoire of models.
2. ***Model construction.*** The composition and structure of each model are specified and expressed mathematically in the form of a preliminary mathematical model.
3. ***Model validation.*** Each model is assessed to determine whether it fulfills as constructed some specific needs in the situation, or needs to be refined or even replaced to this end.
4. ***Model analysis.*** Once a model is validated, analysis can proceed to fulfill the purpose for which it is being constructed. In solving textbook problems, model analysis consists primarily of processing a mathematical model, getting answers to the questions asked in the problems, and interpreting and justifying the answers.
5. ***Model deployment.*** Once a model is validated and analyzed in a particular situation, one needs to extrapolate the new experience. Such extrapolation includes *fine-tuning* any of the model's dimensions and involved concepts, setting conditions for *transferring* the model to new situations, and integrating the refined model in one's own knowledge base.

Fig. 5. Stages that learners should be guided through in modeling paradigm situations.

The content of a conventional science course is regarded as a dogma that is conveyed to the learners following a rigid syllabus (item 6 in Fig. 1). At any given time, all learners are infused with the same dose and through the same means (often by lecture and demonstration). Modern educational theories call for an adaptation of the content of a course to learners' initial knowledge state. OBE and IME comply with this call but to different extents. Under OBE, syllabi often consist of major headlines, and every teacher is left to fill in the details, often on ongoing basis without the use of any instructional manual. This though requires that teachers be: (a) well versed in educational research and theory as well as in the epistemology of science, and (b) assisted by staff bodies that no school can afford. IME draws upon educational research to prescribe flexible classroom modeling activities that can be easily adopted by all teachers, irrespective of their background. The "outcomes" are explicitly spelled out in the form of templates (Fig. 3) that are readily usable by every teacher, and that learners are guided to achieve following well-defined rules (Fig. 5). Learners' initial knowledge state is accounted for during the process in a manner discussed in the following section.

Methodology

Conventional instruction of lecture and demonstration is teacher-centered. The teacher behaves like a preacher who addresses the learners like subservient parishioners. Their minds are treated as empty vessels where scholarly knowledge can be poured in so that it is ready for consumption by the learners any time it is called upon by the teacher. Eger (1993) best describes the situation in science education by saying:

> In educational practice... scientific knowledge [is viewed] as *transferable commodity*. In this view, knowledge, or information, is *produced* in the laboratories, observatories, computer centers, and on researchers' desks; it is then recorded in papers, in monographs, and in books on various levels of expertise; finally through lectures, courses, popularizations, and the work of teachers, that *same* knowledge (information) is *transmitted* to other scientists, to students, and to

> the public. This is the *sender-channel-receiver* model of information theory. It gives us the research scientist as producer-sender, the textbook and teacher as channels, and the student as receiver. When it leaves the hands of the scientist-producer, the commodity (scientific knowledge) is fixed and finished; thereafter, the only way to measure the quality of the transmission is to compare that commodity, as the student receives it, with its form as the scientist sends it. (p. 20)
>
> Thus the teacher is portrayed as the *retailer, and* the student as the *consumer* of science's cognitive products; and thus they see themselves as *outsiders* to science 'itself', identified with the production process. The subject/object distinction is not only taken for granted in this view, it *reifies* everything in sight. (p. 323)

OBE and IME, like all modern educational theories, call for a learner-centered science education that *forms* the mind rather than *informing* it, and that brings the learners into the world of science. To this aim, in IME, like in OBE, learners are actively engaged in the learning process through hands-on and reflective activities (items 1 and 5 in Fig. 1). In a typical IME physics class, the laboratory is integrated with the theoretical part of the course, and learners are constantly confronted with real world situations that they need to model, individually or in groups, using laboratory equipment, computer simulations, and/or paper-and-pencil. Learners' own knowledge is accounted for in the process.

Research has constantly shown that, in science and especially physics, learners bring to their classes deep-seated beliefs about the physical world and education. Learners' conceptions about the physical world are often incommensurable with scientific theory. In conventional instruction, these conceptions are not accounted for; the incommensurability is not resolved and scientific knowledge is often not assimilated (Halloun & Hestenes, 1985). Furthermore, under such instruction learners are led to believe that scientific theory can be learned by rote and that scientific skills can be developed by blindly mimicking the teacher (Halloun & Hestenes, 1998). Under OBE and IME alike, learners are helped to evolve into the scientific realm through reflective and collaborative engagement in the learning process (items 3 and 5 in Fig. 1). Under IME, this evolution takes place by helping learners construct scientific theory on their own through *interactive* modeling activities. During the process, learners are constantly urged to debate their ideas with their peers and resolve any incommensurability with scientific knowledge (Fig. 6).

Figure 6 outlines a *dialectical approach* of instruction whereby individual students are guided to first become aware of the state of their own knowledge and then evolve through the evaluation of their constructs and the negotiation of their meanings and validity with external evidence and with their peers. As indicated in this figure, and based on the degree of commensurability with scientific constructs, student initial constructs can be of three types. Some initial constructs may be *commensurable* with the desired scientific constructs. Others may be *incommensurable* in various respects not only with scientific constructs but also with one another. Finally, some of the desired constructs may have no counterparts in a student's knowledge base, and thus are *novel* to the student in the strict sense of the word. As outlined in Figure 6, the three types of constructs need to be treated differently in science instruction (Halloun, 1998).

Learners' conceptual evolution into the scientific world can be meaningfully achieved when they are afforded to negotiate their individual constructs with their peers and the teacher within the context of paradigm situations. Individual learners must be given the opportunity to defend their own position, challenge others' positions, and slip in others' shoes so as to see the pro's and con's of any argument both from one's own perspective and others'. Only then can learners be transformed from passive recipients of canned knowledge to critical seekers and active producers of generic knowledge.

Modeling paradigm situations is optimized with the integration of modern technology, and especially computers. Computers must be integrated in instructional design not as luxury tools, but as efficient learning tools. When used properly, these tools can enhance the quality of interaction among students and between them and the real world (Redish, Saul & Steinberg, 1997; Thornton & Sokolof, 1990).

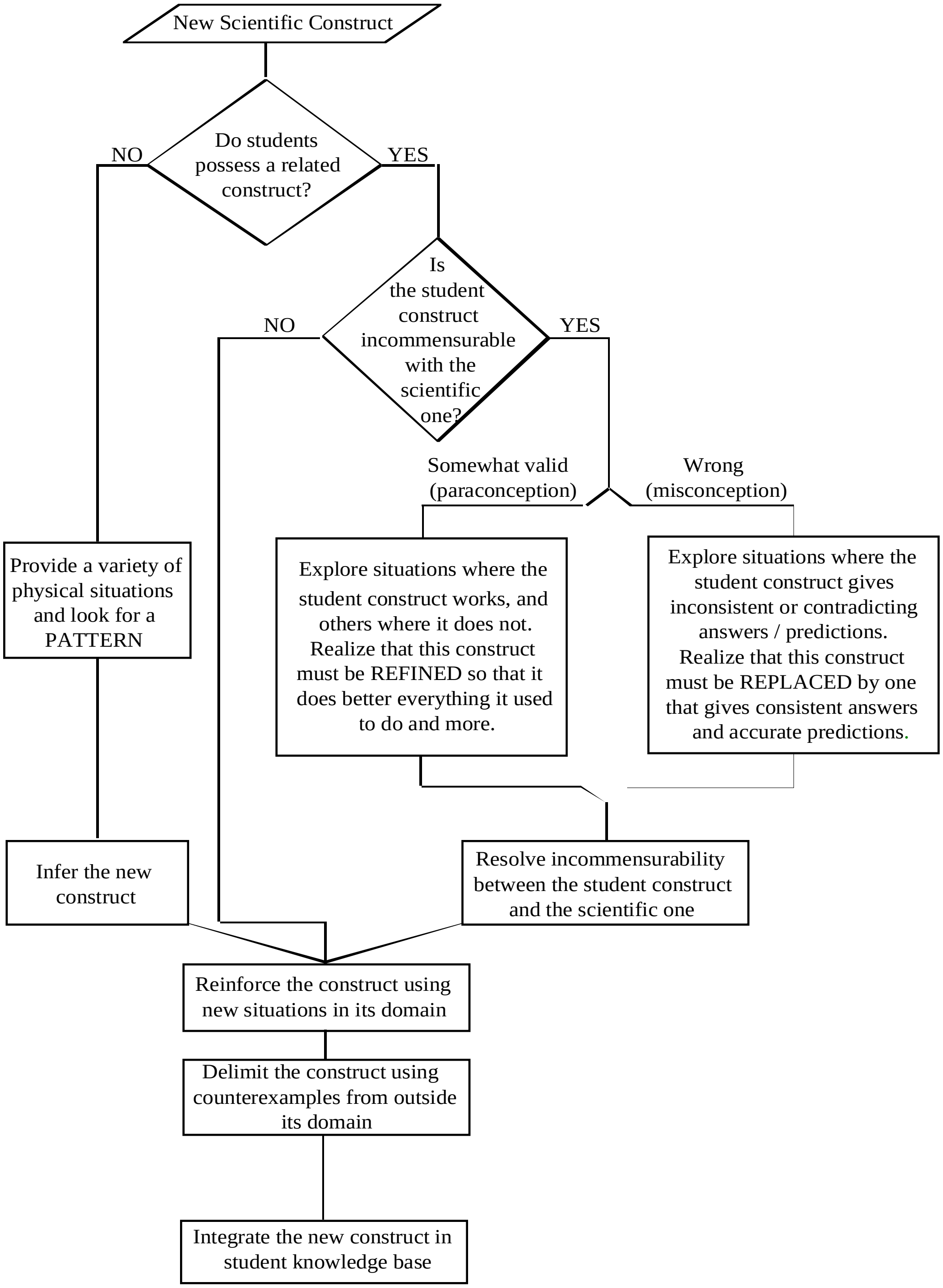

Fig. 6. Toward commensurability between student and scientist constructs (Halloun, 1998)

Learners differ not only with respect to the initial knowledge state that relate to the course at hand, but also with respect to the skills required to evolve into the final state set in the course (outcome). Consequently, IME agrees with OBE on the necessity of not placing content into rigid time frames (item 9 in Fig. 1). However, no educational system can afford having learners "work at their own pace" in the absolute sense. Good athletic coaches adapt the level and period length of a drill to the fitness of individual players in a way that allow players in a team to be all evenly ready for a match with another team. Similarly, under IME, teachers adapt the quality and quantity of their assignments to the needs of individual learners so that, at specific times, all learners could reach in principle about the same outcomes. The so-called individualized instruction that was much hailed many years ago used to allow individual learners work at their own pace along the lines of what is being advocated nowadays by some OBE followers. The downfall of individualized instruction should be a lesson to remember.

OBE often promotes the radical constructivist idea that teachers be "guides on the side" almost leaving it to the learners to determine how learning proceeds. IME does not downplay the role of the teacher to that extreme. Under IME, teachers have to *mediate* learning at different levels. In addition to monitoring and often guiding collaborative and reflective activities, there are times when the teacher has to scaffold some constructs and demonstrate some skills, especially when these are completely novel to the learners. Assessment plays a central role in the learning process as described below, and the teacher is the key figure there. At any rate, and until we can get the knowledge and technology that can help people learn scholarly knowledge, and especially science and mathematics and their applications in technology, without going to school, there can be no learning there without teaching. But for teaching to result in meaningful learning, it has to follow an IME-like approach and not the conventional approach of episodic indoctrination.

Assessment

Conventional instruction is exam-driven (item 2 in Fig. 1). Learners often conceive exams as mere ranking tools that are imposed on them by an external authority so that they be compared in an intimidating manner to their peers and the teacher. They also see passing these exams as the sole target of instruction, and strive to do well on them more to please the teacher and their parents than anything else. Furthermore, they often see that success in these exams depend more on the personality of the teacher than on personal effort (Halloun & Hestenes, 1998). Under OBE and IME alike, exams are meant for the learner as tools of self-evaluation and intellectual development, and for the teacher as means of efficient feedback and for getting learners motivated to assume responsibility for their learning (item 7 in Fig. 1).

Traditional paper-and-pencil exams are not as much downplayed by IME as by OBE. In IME, such exams are conceived as efficient tools for learners to reflect on the state of their knowledge. The outcomes are then used as stepping stones towards the resolution of any incommensurability between learners' own knowledge and scientific knowledge. One way to achieve this goal is to administer periodically short-term quizzes. The same quiz is given twice. The first time around, the quiz is returned to the learners by simply pointing out what was done right and wrong in individual copies. The quiz is then returned to the learners for self-correction and/or for peer correction. This is best done in the classroom through teamwork, and through think aloud and peer critique. A day or more later, a parallel version of the quiz will be given and graded this time around in a traditional manner. This process can be facilitated and rendered more efficient through the use of computers.

Various types of authentic assessment means are promoted by OBE as well as by IME. These means include short term and long term projects, individual and collaborative ones. They are intended to allow learners apply what they learn in the classroom in real world settings, so that they realize, on the one hand, the relevance of scholarly knowledge to everyday life; thus, their curiosity gets stirred and they become motivated to learn things meaningfully. On the other hand, through such projects, learners would be able to better realize the domain of applicability of scholarly knowledge in the real world, a major educational aspect that is often ignored in conventional instruction.

In summary, interactive model-based education engage learners interactively in the construction and application of well-defined, model-centered scientific theories, in order to help them evolve into the realm of science. The outcomes of education are spelled out explicitly in IME with respect to both the content of scientific knowledge and skills that learners ought to develop. Learners are guided to structure coherently every scientific theory around a few basic models of well-defined dimensions. These models are constructed and applied in paradigm situations that are designed to help learners evaluate their initial knowledge state and develop skills of scientific inquiry. To this end, learners are constantly urged to think aloud and negotiate their own ideas with their peers while modeling the physical world cooperatively. The teacher has to constantly monitor and regulate the pace of learners’ activities, scaffold new knowledge whenever needed, and assess learners in a way that help them identify their weaknesses and strengths and motivate them to evolve into the realm of science.

How effective is IME?

Since the early eighties, IME has been implemented to various degrees in secondary school and college physics, in Lebanon and USA (Halloun & Hestenes, 1987; Halloun 1994, 1996 & 1998; Hestenes, 1997; Wells, Hestenes & Swackhamer, 1995). The effectiveness of this educational approach is being constantly measured using various tools. Teachers are surveyed to ascertain how they are implementing IME, and evaluate, from their own perspective, their practice and learners’ involvement and their understanding of physics. Learners under IME are compared to their peers who follow conventional physics instruction, based on their performance on standardized tests for assessing conceptual understanding (Halloun & Hestenes, 1985; Hestenes, et al. 1992), and regular problem solving tasks (Halloun, 1994 & 1996), as well as on their overall classroom performance as measured by teachers’ grades. All forms of evaluation are constantly showing that IME is significantly superior to conventional instruction, especially in the following respects.

Teachers constantly report that:

- models in IME provide a strong thread that tie the various physics constructs together in a more coherent and more easily accessible format for the students than the traditional episodic format.
- modeling paradigm situations along the lines of Figure 5 helps learners best develop scientific skills, especially of critical inquiry. More importantly, learners are reported

to successfully transfer modeling skills that they develop in specific situations into novel situations, within and outside the domain of training.

- the interactive, dialectical approach is in and of itself motivating both for them and for their pupils and students. Many teachers are especially surprised at what lower level learners could do under such approach, and report that the learners themselves are getting surprised and pleased at their ability to reason.

Learners' assessment, on the other hand, is constantly showing the following:

- By comparison to conventional instruction, under IME, learners average about 1.5 standard deviations higher on standard instruments for assessing conceptual understanding of physics.
- While under conventional instruction at best 5% of secondary school pupils and 20% of college students are able to solve various regular textbook problems administered for comparative evaluation, the rate of success under IME rises to at least 34% in secondary schools, and 72% in college.
- Under IME, overall course performance, as measured by identical or similar exams and assignments, can be about twice as better than under conventional instruction, and attrition rates can be reduced to less than one third of what they are under the latter.

IME is expected to yield increasingly better results in the future. Results reported above pertain to either constrained classroom experiments or to courses where IME is being implemented by teachers who are still under training. Still, no form of OBE or any other non-conventional educational approach has ever been able to match IME's results in physics. Given its generic nature, there is no reason to doubt that, when applied to other scientific disciplines as well as mathematics, IME could result in comparable results there.

A word of caution is perhaps due at this point. No one should expect contiguously phenomenal results under IME. Like any new educational approach, teachers who want to adopt IME need excessive training for a number of semesters before they could fully implement it in their classrooms (perhaps more so for OBE than IME). A support system needs also to be instituted thereafter to ensure that teachers are well on track, on the one hand, and to assist them in times of need, on the other hand. The cost may thus seem too high for a country to pay in order to significantly deviate from the status quo. Nevertheless, given the uncertainties of OBE and the relatively higher expenditures that individual schools have to sustain for implementing it, IME remains a more viable alternative for significantly improving science (and mathematics) education.

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