# Opinion Page

## Opinion Piece: Time to heed the alarm raised 35 years ago over a continuing failure in science learning, Ibrahim A. Halloun

H Institute
P. O. Box 2882, Jounieh, Lebanon

4727 E. Bell Rd, Suite 45-332,
Phoenix, AZ 85032, USA

Email: halloun@halloun.net or halloun@hinstitute.org
Web: http://www.halloun.net and http://www.hinstitute.org

Thirty-five years ago, we published two complementary articles[1] in the *American Journal of Physics* about the *Mechanics Diagnostic Test* (MDT) originally developed as part of my PhD dissertation at Arizona State University (ASU) on model-based instruction of Newtonian theory:

Four major results came out of administering MDT to high school and college students:

1. Students come to their physics courses with common sense (CS) beliefs about the motion of physical objects that are at odds with Newtonian theory.

2. These beliefs, often labelled as naive, lay, or folk beliefs or conceptions, misconceptions, or alternative conceptions, are deeply rooted in students' minds as part of their overall CS paradigms, and common modes of science instruction do very little to subdue these beliefs and paradigms.

3. CS paradigms govern students' cognitive processes and prevent them from meaningful learning of scientific theory and thus from correct interpretation of real world systems and phenomena.

4. Students may successfully pass course exams by reproducing course materials they learned by rote and retained by heart in their short-term memory. The same students often fail drastically on the same exams given awhile later, indicating that assimilated science materials either did not make their way to student long-term memory (LTM) or, if they did, these materials are being inhibited from activation by CS paradigms that are tenaciously sustained in student LTM.

[1] Halloun, I., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics*, 53 (11), 1043–1055.
Halloun, I., & Hestenes, D. (1985). Common sense concepts about motion. *American Journal of Physics*, 53 (11), 1056–1065.
The two articles became the 1985 *Most Memorable Articles* of the *American Journal of Physics*. *AJP*. (1993). 61 (2), 103–105.

Other diagnostic tests and inventories were developed before and after MDT in physics and other scientific fields all coming, until the present day, to results similar to the ones indicated above in the respective fields. In fact, student beliefs about physical systems and phenomena that are at odds with scientific theory have plagued science education for ages almost like a terminal cognitive pandemic. These beliefs can, and must, be understood within the framework of ordinary people common sense (CS) paradigms. According to such naturally predominant paradigms, and among other things, the reality of physical systems and phenomena is exposed directly to our senses, and thus most ordinary people believe that the Sun turns around the Earth because this is the way it appears to us.

About four centuries ago, Galileo Galilei, the father of modern science, taught us that this is far from being true and that direct human perception is often deceiving. Thus, in order to understand the universe, we have to transcend our perceptions and imagine how the world could actually exist in a way that is not exposed directly to our senses. As such, we can then realise that the Earth turns around the Sun and not the other way around. In this and many other respects, scientific paradigms are counterintuitive, which makes it hard to let them prevail over CS paradigms in students' minds without resolute and purposeful efforts in this direction in formal education beginning at an early age.

Traditional science curricula that work primarily on conveying specific aspects of scientific theory – often haphazardly selected – cannot help students achieve such prevalence, not to mention a Galilean paradigm shift. That is why calls have reverberated, and efforts been deployed within the educational community for decades now to change course, but unfortunately often to no avail. Changes brought about in the desired direction by a given group or individual have been hardly sustained, if any, and rarely reproduced at the same level of success by concerned others. Looking at the broad spectrum of high school and college students, researchers keep getting results similar to the ones we published 35 years ago, with no systemic reform producing desired large scale changes. Our experience suggests that, no matter how gloomy the situation may actually look, there are effective ways to turn things around and bring the so far obstinate cognitive pandemic of CS paradigms under control.

MDT was originally developed not for its own sake, but as part of a battery of instruments designed to ascertain the efficiency of a modelling pedagogical framework that I first conceived at ASU for my PhD dissertation[2], and continued developing afterwards in collaboration with colleagues at ASU and elsewhere. From start, development of the modelling framework went along two complementary directions that any pedagogical framework needs to address and that we will hereafter refer to as academic and cognitive dimensions addressing respectively "what" and "how" to teach and learn, first in physics and then in science3.

The academic dimension needs to reveal in every possible detail what a given discipline like physics (or field like science) is about, how its episteme is organised, and how professionals in that discipline go about setting and achieving their goals. In this respect, we defined scientific models and modelling processes and transformed them from conceptual tools and research methodology for scientists to describe and explain patterns in the structure and/or behaviour of physical realities (real world systems and phenomena) to pedago-

[2] Halloun, I., & Hestenes, D. (1987). Modeling instruction in mechanics. *American Journal of Physics*, 55 (5), 455–462.

gical means for students to understand such realities meaningfully and answer questions and solve problems about them successfully and creatively. Under the modelling pedagogical framework3, we thus hold that:

1. science is primarily about the description and explanation of patterns in the structure and behaviour of physical systems;
2. scientific episteme consists of scientific theories, with each theory organised around a limited number of conceptual models representing in specific respects particular real world patterns;
3. scientists construct, corroborate, and deploy conceptual models systemically and systematically to reliably interpret physical realities (describe and explain respective patterns) and deal with them creatively and innovatively (infer their past and predict their future, control and change their states, and invent related artefacts); scientific models and modelling allow for a coherent big picture and efficient knowledge transfer within and among different scientific disciplines, and for efficient and practical convergence between these and non-scientific disciplines;
4. any science curriculum should thus be primarily about scientific models and modelling, and any science course should be organised explicitly around a small set of models that show well enough how the respective scientific theory serves its function at a level that matches students' cognitive potentials.

The cognitive dimension needs to prescribe, based on reliable research in cognitive science and neuroscience, how students may achieve meaningful understanding of the academic perspective above and develop their paradigms and profiles to reasonable levels. In this respect, we devised the modelling cycle as a comprehensive methodology of experiential learning for model construction and deployment and insightful regulation of student common sense conceptions and practices. More specifically, under the modelling pedagogical framework[3]:

1. students are engaged, individually and in groups, in experiential learning cycles for model construction and deployment (modelling cycles);
2. students rely on a systemic schema, a generic template for constructing any conception (concepts and relations among concepts) in any field, to construct any scientific model and spell out, under a specific framework (scientific theory), and in accordance with a well-defined taxonomy of learning outcomes, (i) the scope of the model (what pattern it represents and what it describes and/or explains about this pattern and model referents, i.e., physical realities manifesting the pattern), (ii) its constitution (what entities make up the model and its environment and how these entities interact and affect the model structure), and (iii) its performance (how and why the model works, or its referents behave, and what are the outcomes);
3. students deploy a generic, systemic scheme for model construction and deployment, including all sorts of problem solving;
4. students are constantly engaged in insightful dialectics for revealing and resolving any issue

[3]Halloun, I. (2001). *Apprentissage par Modélisation: La Physique Intelligible*. Beyrouth, Liban : Phoenix series/ Librairie du Liban.

Halloun, I. (2004/2006). *Modeling Theory in Science Education*. Dordrecht, NL: Kluwer/ Springer.

within their own paradigms, in correspondence to the real world and in commensurability with scientific paradigms;

5. teachers plan efficient modelling cycles, with each cycle dedicated to student construction and deployment of one particular scientific model under teacher mediation involving Socratic dialogues and timely intervention tailored to students' individual needs.

Colleagues and student teachers have been implementing the modelling pedagogical framework for over thirty years at the college and pre-college levels. Through systematic comparative evaluation of these teachers' and their students' performance, we have been able to identify a number of factors that are critical for any pedagogical framework, and not only the modelling framework, to succeed making scientific paradigms prevail over CS paradigms in students' long-term memory (LTM).

The success in question is primarily determined by the nature of, and relative adherence to, the pedagogical framework under which a curriculum and related courses are designed and implemented. Any curriculum, and thus any course at any educational level, must be designed and implemented under a well-defined pedagogical framework that addresses evenly and explicitly both academic and cognitive dimensions. Missing or playing down any dimension in any respect in course design or implementation prevent students from developing meaningful and sustainable scientific knowledge that prevails over CS beliefs and paradigms in their LTM.

Epistemic and methodological idiosyncrasy and fragmentation are major persistent flaws in student knowledge before and after science instruction. Students fail to develop a coherent conceptual picture of science and fail to deploy scientific knowledge consistently and systematically across similar and different contexts. They are thus incapable to transfer what they assimilate in class within and across courses. Scientific models and modelling processes readily allow for convergence within all scientific fields and disciplines. As conceptual systems representing real world patterns in the structure and/or behaviour of physical systems, scientific models also allow for convergence with non-scientific fields and disciplines. This would especially be the case when curricula outside science are conceived under systemic pedagogical frameworks that emphasise the importance of physical and conceptual systems of all nature in developing a meaningful and productive picture of the real world and the conceptual realm of professionals in all fields.

To succeed meeting their ends, any pedagogical framework and any curriculum should have reasonable expectations about both students and teachers so that both groups may willingly, constructively, and efficiently achieve what is expected of them. Curriculum developers and teachers should be well aware of what students can actually achieve, and how they can feasibly do so, at specific points of instruction, given their natural cognitive state and their educational background. They should especially know how neuro-cognitive maturity determines learning, somewhat in the Piagetian sense, and how learning can determine neuro-cognitive growth, somewhat in the Vygotskian sense. Cognitive science and especially neuroscience are indispensable in this respect.

Meanwhile, curriculum developers, teacher education institutions, and education authorities and administrators should all have reasonable expectations of what teachers can achieve with their students given, among others, their professional background and the state of the entire ecology in which they are working, including the state of their students, available resources, and workload and compensation.

Finally, teachers have to be trained and treated as professionals, and they have to carry out their mission as such. Once in-service, teachers cannot, and should not, be left on their own. Appropriate systems, platforms, and mechanisms should be in place to continuously monitor students and teachers, provide timely support for teachers in need, and ensure efficient sharing of best practices (through some sort of "communities of practice" like professional learning communities) and continuous professional development for all teachers. Moreover, teachers and all other stakeholders must constantly be supported to heed and meet any challenge that may arise, including unprecedented qualifications and needs that could eventually emerge in the job market and various aspects of life and that education must prepare students for.

The modelling pedagogical framework is not a traditional didactic framework for lecture and demonstration about scientific bits and pieces. It is about teacher-mediated student development of meaningful and productive model-based scientific theory and paradigm, including generic means and methods for insightful and regulatory knowledge development, and thus for helping students (and teachers!) transcend their CS paradigms. Teachers need intense clinical training to master and efficiently deploy such a framework, including continuous workshops and support while in service. Our experience suggests that teachers can do significantly better and be more at ease if: (a) the framework is part of their pre-service education at the undergraduate and graduate levels, and (b) curricula they implement are conceived in this framework or another framework that can accommodate, or be adapted to, modelling tenets and principles in both academic and cognitive respects.

Common sense beliefs revealed by MDT and similar inventories are not held by students about specific physical systems and phenomena in isolation of other thoughts and practices. These beliefs stem from overall CS paradigms that govern everything students and other ordinary people think about, and do with, physical realities. Counterpart, scientific paradigms are largely counterintuitive and hard to consider and develop without formal education under appropriate pedagogical frameworks that take into consideration the state of mind of both students and scientists. The modelling pedagogical framework is such a framework, and it has proven viable in over thirty years of practice and continuous development at the college and pre-college levels. With proper training and support, understanding and appreciation of concerned authorities (!), and under appropriate frameworks like the modelling framework, teachers can heed resolutely the alarm we raised 35 years ago and tame down students' CS paradigms to the extent of having scientific paradigms prevail meaningfully in their long-term memory.

These matters and more are elaborated in the expanded version of this paper available here and here.