Erice Statement on the Critical Importance of Molecular Life Sciences Education: A Global Call to Action

Anna Pascucci[1]*, **Miguel Allende[2]**, **Carol O'Donnell[3]**, **Peter McGrath[4]**, **Chris Bowler[5]**, **Marty Samuels[6]**, **Davide Cacchiarelli[7]**, **Alia Qatarneh[8]**, **Badin Borde[9]**, **Joe Niemela[10]**, **Cristina Miceli[11]**, **Francesca Gale[12]**, and **Bruce Alberts[13]**

1. Ettore Majorana Foundation and Centre for Scientific Culture, International School of Science Education (ISSE), Erice, Italy; **2**. Millennium Institute Center for Genome Regulation (MI-CGR), University of Chile, Santiago, Chile; **3**. Smithsonian Science Education Center, Washington DC, USA; **4**. InterAcademy Partnership (IAP), Trieste, Italy; **5**. CNRS, École Normale Supérieure (ENS), Paris, France; **6**. Columbia University, New York, USA; **7**. University of Naples "Federico II"(UNINA) and Telethon Institute of Genetics and Medicine (TIGEM), Naples, Italy; **8**. Harvard Graduate School of Education, Boston, USA; **9**. Siemens Stiftung, Munich, Germany; **10**. The Abdus Salam International Centre for Theoretical Physics (ICTP) – UNESCO, Trieste, Italy; **11**. University of Camerino (UNICAM), Camerino, Italy; **12**. Wellcome Sanger Institute, Cambridge, UK; **13**. University of California, San Francisco, USA.

**Corresponding author: pascucci.isse@gmail.com*

Why learn molecular biology?

"The *key to every biological problem must finally be sought in the cell*; for every living organism is, or at some time has been, a cell." This statement, written by the great American biologist E.B. Wilson (1856-1939), provides a powerful impetus for today's efforts to share our understanding of how cells function at the molecular level through the teaching of "molecular biology".

The cell is fundamentally a self-replicating collection of catalysts. And thanks to the efforts of thousands of scientists and educators who share knowledge and skills with learners, we now know a great deal about how the molecules of the cell—especially its protein, DNA, and RNA molecules—work together to create the complex core of the remarkable system that generates and sustains life. Continuously re-engineered and diversified by evolution, with species networked together within ecosystems, this self-replicating chemical machinery is shared by every living organism on planet Earth—by every animal, every plant, every fungus, and every bacterium.

Molecular biology serves as a key that unlocks our understanding of the molecular choreography of the cell and its interactions with the environment, revealing how its components act together to sustain life.

Why do we believe that attaining a basic understanding of the system that underlies all life should be one of the fundamental goals for a high school education?

Firstly, it is thrilling, inspiring, and an enormous privilege to gain an understanding of how life is possible, including human existence. We are made of cells, we feed on cells, and our world is made habitable by cells – the cells that make up the bodies of all the biodiversity with which we share our planet.

But there are also many practical reasons for making molecular biology a part of everyone's education. All of us, as citizens of Earth, need to know something about this subject to grapple with the modern world. Over the past decades, the scope of investigation in molecular biology has expanded enormously to create the *field of molecular life sciences*, which expands molecular biological insights and technologies into *broader biological, medical, environmental, and societal contexts*. Landmark achievements include

- **Genomes and genes in action.** Thanks to the Human Genome Project and powerful new tools such as RNA-Seq and, more recently, single-cell and spatial transcriptomics, scientists can now map gene expression across the entire genome with unprecedented resolution—down to the level of individual cells and their spatial organization**.** This makes it possible to uncover cellular heterogeneity and the

molecular basis of complex tissues and diseases, insights that were unimaginable just a few decades ago.

- **Proteins and molecular networks.** Modern proteomics, supported by advanced methods such as mass spectrometry and computational modeling, reveals that life is governed not by isolated molecules but by dynamic, interconnected networks that constantly communicate and adapt.

- **From understanding to application.** Breakthroughs such as CRISPR-Cas gene editing, engineered plants and microbiomes, and precision medicine—and, most strikingly, the unprecedentedly rapid development of mRNA vaccines against COVID-19—demonstrate how molecular discoveries can be mobilized into life-saving applications within record time, with profound impact on global health, food security, and the environment.

- **The future frontier.** Artificial intelligence, machine learning, and other emerging molecular technologies are now enabling predictive models of protein folding, disease mechanisms, and drug discovery at a scale that was not possible before, opening new directions for both science and society.

Molecular research today is *a domain of inquiry that bridges fundamental research and real-world applications*, connecting molecular mechanisms to human health, biodiversity, sustainability, and the development of many new technologies. This integration justifies expanding our educational focus from traditional molecular biology to *molecular life sciences as a field of study***,** emphasizing the broader relevance and societal impact of our ever-expanding molecular knowledge.

.

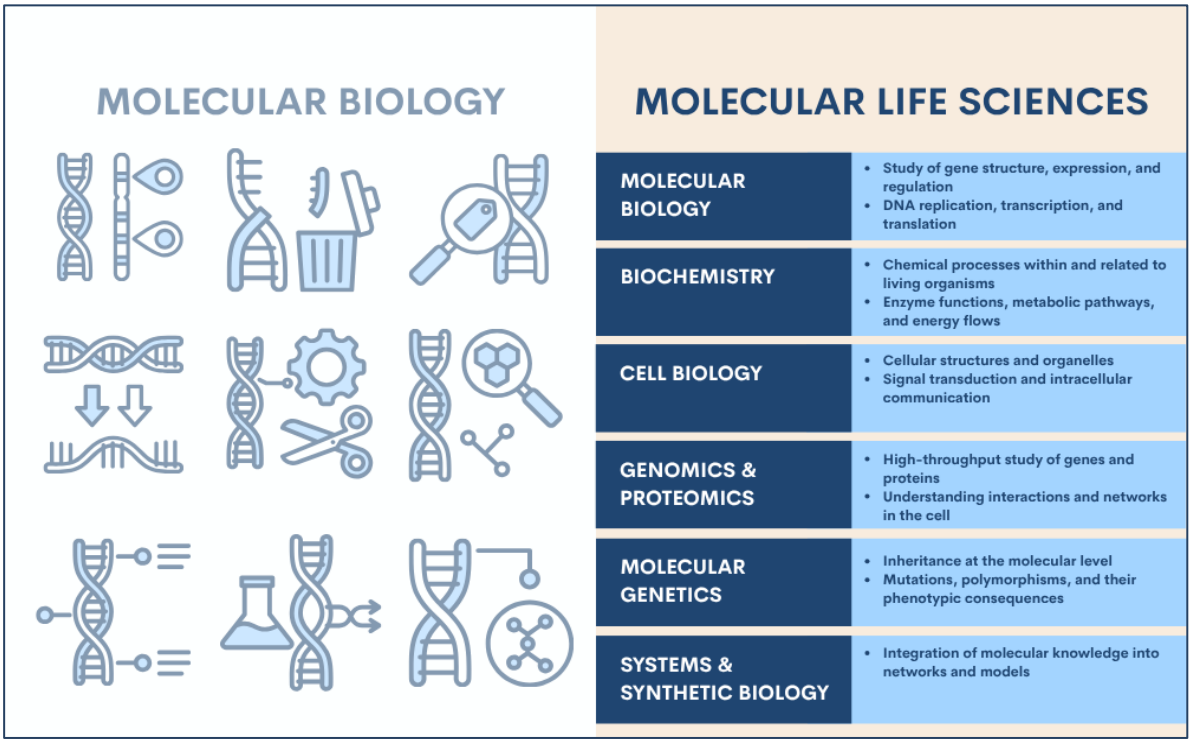

Figure 1

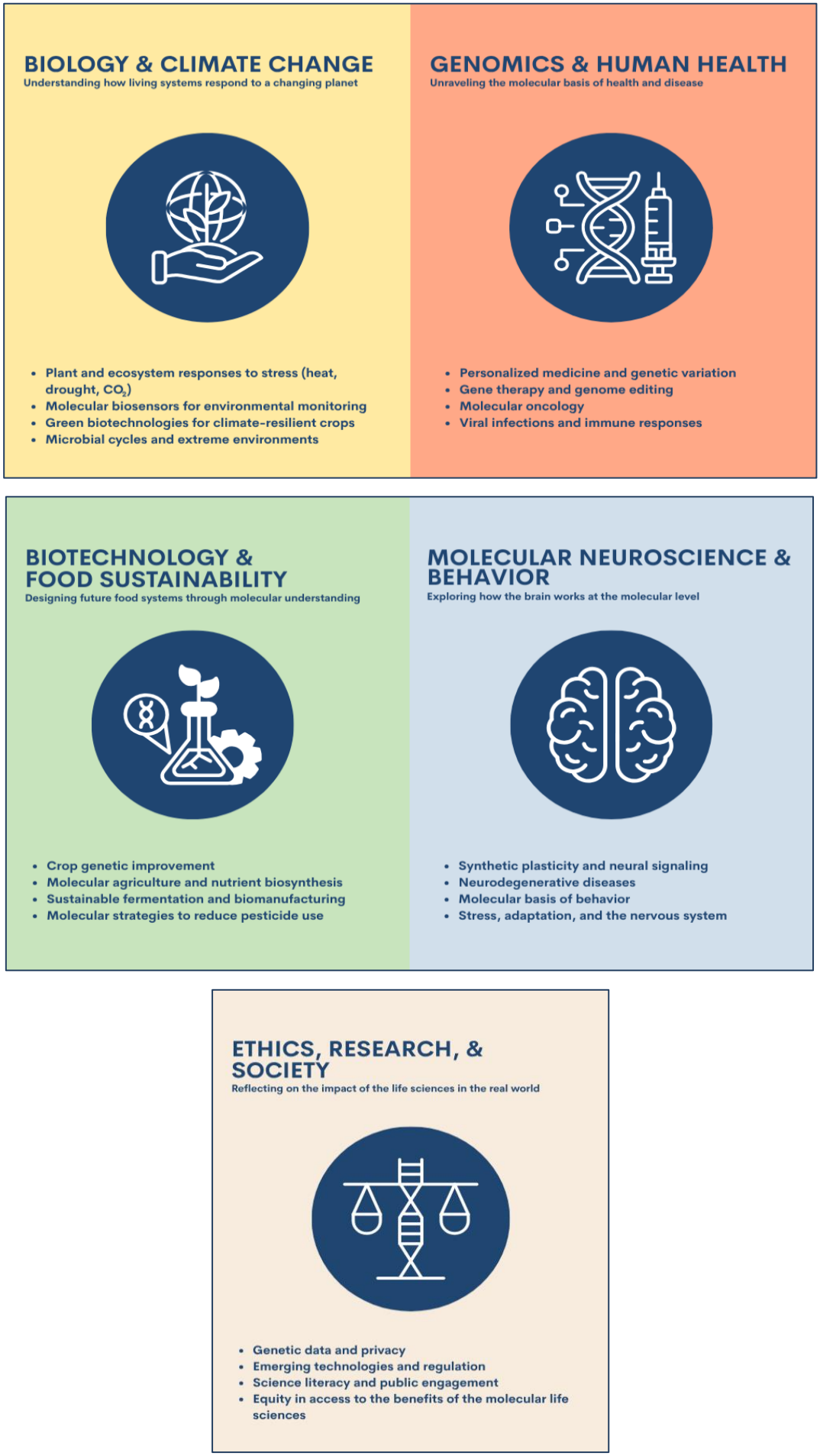
BIOLOGY & CLIMATE CHANGE
Understanding how living systems respond to a changing planet
Plant and ecosystem responses to stress (heat, drought, CO_2)
Molecular biosensors for environmental monitoring
Green biotechnologies for climate-resilient crops
Microbial cycles and extreme environments
GENOMICS & HUMAN HEALTH
Unraveling the molecular basis of health and disease
Personalized medicine and genetic variation
Gene therapy and genome editing
Molecular oncology
Viral infections and immune responses
BIOTECHNOLOGY & FOOD SUSTAINABILITY
Designing future food systems through molecular understanding
Crop genetic improvement
Molecular agriculture and nutrient biosynthesis
Sustainable fermentation and biomanufacturing
Molecular strategies to reduce pesticide use
MOLECULAR NEUROSCIENCE & BEHAVIOR
Exploring how the brain works at the molecular level
Synthetic plasticity and neural signaling
Neurodegenerative diseases
Molecular basis of behavior
Stress, adaptation, and the nervous system
ETHICS, RESEARCH, & SOCIETY
Reflecting on the impact of the life sciences in the real world
Genetic data and privacy
Emerging technologies and regulation
Science literacy and public engagement
Equity in access to the benefits of the molecular life sciences

Figure 2

Why Molecular Life Sciences Education Matters

As a subject in science education, Molecular Life Sciences can also support broader educational goals. The COVID-19 pandemic starkly revealed the dangers of widespread scientific illiteracy—not only regarding molecular knowledge, but also in understanding how science works, how to assess trustworthiness, and how scientific knowledge contributes to human well-being.

The future of humanity may depend on developing and providing schooling that cultivates a "scientific habit of mind": including curiosity about nature, the practice of asking questions, and the rigorous attempt to answer those questions using evidence and data, thereby contributing to a society that cares deeply about the use of scientific evidence to inform decision-making and that demands evidence from those who seek to downplay or counter scientific knowledge.

Science has often been taught in a purely transmissive way as a mass of disconnected "facts" to be memorized, and these are typically quickly forgotten by uninspired students. However, teaching practices evolve over time. Current education research demonstrates that the scientific knowledge, understanding, skills, and attitudes needed by all students (whether or not they go on to further study or explore science-based careers) are best developed through Inquiry-Based Science Education (IBSE) – in which students progressively develop key scientific ideas by learning how to investigate and extend their knowledge and understanding of the world around them. Here, they develop a deep respect for evidence and use skills employed by scientists, such as defining problems and raising questions, collecting and analyzing data, examining, reasoning, and arguing from evidence in the light of what is already known; drawing conclusions (or designing solutions); and discussing findings.

Molecular Life Sciences education that incorporates IBSE can also help to inspire the next generation of researchers, providing educators with many opportunities to illustrate how fundamental scientific research has repeatedly developed knowledge and tools to bring great benefits to humanity, from specific medical advances that they might otherwise take for granted, to improving the food supply.

And finally, there is a need for everyone to learn how the scientific community produces reliable knowledge – to understand that scientific judgements are not based on opinion, but on the cumulative and ongoing work of scientists around the world, who continuously generate results, pool their data, and critically evaluate one another's findings, techniques, and conclusions. This understanding is best fostered by intentionally using IBSE education, including Molecular Life Sciences education, to teach both the importance of scientific consensus and the dynamic, evolving nature of scientific knowledge.

To summarize, we envision four critical goals for Molecular Life Sciences education, which might be concisely stated as follows:

- Draw on real-world scientific phenomena to *inspire* students with the wonder of life and an understanding of how it is possible.
- *Engage* students as directly as possible with scientific phenomena in and out of the classroom, so that they develop an understanding of the role of fundamental research and the benefits it brings to humanity.
- *Prepare* students to assess evidence and apply critical thinking, with the knowledge, skills, practices, and abilities to grapple with the numerous health, environmental, and other decisions they will face throughout their lives.
- *Encourage* students to seek evidence to explain scientific phenomena, so that they gain respect for a scientific consensus based on the preponderance of evidence, such as that for climate change or vaccines.

Toward a Global Alliance for Molecular Life Sciences Education

This vision invites us to act together.

To truly realize the promise of Molecular Life Sciences education, we must move beyond individual programs and national boundaries. International efforts such as UNESCO's Open Science framework already point in this direction, underlining the importance of global collaboration in education and of ensuring equitable access to scientific knowledge worldwide. We therefore propose a new Global Alliance: a collaborative, inclusive, emergent, and sustained effort among scientists, educators, youth, institutions, and networks committed to transforming the way we teach, learn, and communicate the molecular foundations of life and their real-world applications.

The Global Alliance for Molecular Life Sciences Education would:

- **Articulate a shared framework** for Molecular Life Sciences education, co-created with teachers and students, grounded in the four core goals outlined above;
- **Foster innovation and equity** by sharing resources, practices, and training models across contexts and continents;
- **Build bridges** between educators and researchers, between policy and practice, between science and society;
- **Create a platform** to influence curricula, funding priorities, and education policy at national and international levels;
- **Support educators**, not only with content and tools, but through professional development and peer communities;
- **Include youth to ensure that learners everywhere**, regardless of geography or background, gain access to this essential scientific understanding.

We believe that such a Global Alliance is not only desirable but also necessary – if we are to prepare the next generation to meet the challenges it will face with knowledge, wisdom, and integrity.

Figure 3