Cell Systems
Letter

The Science of Living Matter for Tomorrow

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The interface of physics and biology provides a fruitful environment for generating new concepts and exciting ways forward to understanding living matter. Examples of successful studies include the establishment and readout of morphogen gradients during development, signal processing in protein and genetic networks, the role of fluctuations in determining the fates of cells and tissues, and collective effects in proteins and in tissues. It is not hard to envision that significant further advances will translate to societal benefits by initiating the development of new devices and strategies for curing disease. However, research at the interface poses various challenges, in particular for young scientists, and current institutions are rarely designed to facilitate such scientific programs. In this Letter, we propose an international initiative that addresses these challenges through the establishment of a worldwide network of platforms for cross-disciplinary training and incubators for starting new collaborations.

Standard training programs in biology and physics usually focus on concepts that are rarely translated from one discipline to the other in a comprehensive manner. One reason is that it typically takes exposure to many different examples to fully grasp the meaning of concepts, and this makes translations very challenging. For example, "signaling pathways" for biologists or "phase diagrams" for physicists represent the expected punchlines for a significant study, sometimes on the very same phenomenon, but it is difficult to convey their meaning in depth to somebody from the respective other field. In addition, young scientists encounter difficulties in publishing their work as many journals, editors, and referees are often not yet prepared to evaluate research at this interface for their relevance. A knock-on effect of this is that junior group leaders are limited in their ambitions by being encouraged to work and publish in a single discipline. This makes it easier for evaluation committees, since they can rely on that discipline's conventions (e.g., ordering of author names, expected publication number, and other bibliometric factors) to form an opinion about the candidate's scientific achievements. Lastly, in spite of many funding bodies claiming to support interdisciplinary research, it is often difficult for grant panels to evaluate interdisciplinary projects (Bromham et al., 2016). All these factors present obstacles for further progress and exploration of new frontiers at the interface of physics and biology.

To tackle these challenges, we ran a symposium at the Champalimaud Centre for the Unknown in Lisbon with the active participation of a lively audience. The speakers were selected for their experiences in setting up programs dedicated to train newcomers willing to work at the interfaces and for their contributions to the interface at an early stage of their career covering several topics, ranging from single molecules to developmental biology and theoretical physics. Biological functions combined with new questions in physics were a common denominator throughout the day. As a result, we have identified several areas—at both the educational and the research levels—that require special attention if young scientists are to be attracted to research at the interface of biology and the physical sciences. Furthermore, we sought strategies to overcome the current difficulties facing interdisciplinary work.

We emphasize that there is a distinction between attracting students to interdisciplinary questions and providing them with the tools to carry out interdisciplinary research. An important conclusion of our discussions is that a deep and thorough study in a single discipline is still a critical component of a scientist's education. However, this must not preclude students from being exposed to ideas in other disciplines. For example, mathematical and physical reasoning can be integrated readily within biology courses (Aikens and Dolan, 2014). Similarly, the education of physicists can more clearly emphasize the successes of quantitative concepts and experiments in biology, and physics students should gain sensitivity toward the rationale of questions relevant to biology. Typically, current curricula poorly integrate these ideas: the focus is placed on paradigms of the field, and students get specialized early on. A larger vision of science helps to broaden the way students think about their scientific questions. At the research level, an underlying thread to most successful interdisciplinary collaborations are daily, personal interactions between researchers from different disciplines in the early stages of a project. Frequent encounters between biologists and physicists are essential for building mutual trust and for raising awareness of the strengths of the respective fields.

We advocate for an international initiative for establishing a worldwide network of *platforms* for cross-disciplinary training and *incubators* for starting new collaborations. Platforms would provide the experimental environment, whereas incubators would generate the intellectual atmosphere to formulate new scientific questions. This initiative is inspired by centers, which were successful in establishing a productive environment for discussing and probing new ideas in informal manners and away from the laboratory environments. Interestingly, these centers were originally started with the specific goal to train students in the very basics of science. For example, the "Les Houches" summer schools started in 1951 to train students in physics after the 2nd World War (https://www.houches-school-physics.com/). Also, the International Centre for Theoretical Physics in Trieste (https://www.ictp.it/) has been instrumental in advancing science in developing countries after its creation in 1964. These centers operate with a small permanent staff and host topical research programs with a duration of several weeks or months. Groundbreaking discoveries have followed in soft matter physics and in quantum mechanics, for example, and their discoverers—among them Nobel laureates and Fields Medal recipients—acknowledge the triggering impact of these stays, away from routine laboratory works and administrative burdens.

The proposed training platforms would offer scientists—from graduate levels up to senior levels—training experience outside of their main discipline. During their visits lasting one month up to one year, trainees could design experiments from scratch, analyze physics models, and compare experiments and theory. In this way, attendees mostly educated in physics could gain hands-on experience with specific biological systems and state-of-the-art experimental techniques employed in biology and face their benefits and limitations. In contrast, scientists mostly educated in biology could deepen their understanding of concepts from physics and develop an idea about the usefulness and limitations of physical models for understanding biological processes. This would enable these scientists to better evaluate the biological significance of theoretical results, to assess their degree of originality, and to conceive potential tests of physical mechanisms in experiments. Beyond the immediate impact of newly acquired competences, higher standards in comparisons between theory and experiments could emerge.

Complementing the platforms, incubators would provide an infrastructure for establishing collaborations. The primary goal would be to probe physical mechanisms in biological systems, many of which could originate from theoretical ideas derived from first principles. To get collaborations started, scientists with very different backgrounds could join an incubator in the form of a retreat or a sabbatical.

Both training platforms and incubators would be designed for visits, which could last from a few months up to a year. The visitors would get access to various experimental systems and state-of-the-art tools that are available at the research institution hosting the incubator or platform. This could include access to infrastructure for working with model organisms, as well as facilities such as microscopy, microfluidics, and others. In parallel with the experimental infrastructure, platforms and incubators could organize computational support for theoreticians. Theoreticians and experimentalists would be expected to work in close collaboration through daily discussions of experimental designs and flow of reasoning.

There would be discussion zones in which all scientists present at the institute hosting the platform and/or incubator could bring in their expertise to help shaping and improving the projects of others. Such interactions are especially important during the early phases of a project. The formats for seminars and discussions would be designed to trigger spontaneous attendance between scientists with different backgrounds. Chalk talks would be favored with freedom for lively interruptions.

Through this direct and daily exposure to people, concepts, and tools from other fields, a shift in ideas and systems could be realized at any stage of a career of scientists. The initiative will be open to group leaders, as well as postdocs and PhDs willing to acquire a new perspective. The visitors would be staying in the hosting institute for the nucleating phase of their projects and return to their home institutions afterward. After their return, they could still benefit from support by the network through advice and (limited) access to the experimental or computational infrastructure. Emphasis would be placed on the scientists themselves performing their own experiments from simple elements and pieces, in contrast to relying exclusively on the available technical supports. The stays would convey the spirit of laboratory retreats and provide total freedom in thinking with no pressure to publish. Still, the success of such a stay would be evaluated. The evaluation could be based on short reports that would be deposited on preprint server with the label of the host institute, to achieve openness, transparency, and accessibility of these projects, and to open new avenues for publishing fresh approaches.

On the scale of the network, a rotating collegium of scientists with a mandate of a couple of years would select and supervise the emerging projects for their innovative nature and their consistency with the profiles of platforms and incubators. They would assure adaptation and continuous updates of the infrastructure and awareness of potential redundancies of research topics. This board could also serve the community by providing constructive feedback and advice all along the project timeline.

Some institutes already exist that are dedicated to research at the interface between physics and biology. They have promoted the interest of a growing community through summer schools and annual meetings, e.g., the Physics of Living Matter Symposia in Cambridge (UK) (http://www.plm-symposium.org). In addition, there are training platforms for students and researchers at various levels in the form of interdisciplinary courses, e.g., the boot camp at the Mechanobiology Institute in Singapore (https://mbi.nus.edu.sg/event/2017-bootcamp-on-mechanobiology/), hands-on research courses like the MBL Physiology and Physical Biology of the Cell summer courses in the US (http://www.mbl.edu/education/courses/physical-biology-of-the-cell/), and specialized master programs such as the Cell Physics

Master at the University of Strasbourg in Europe (http://www.cellphysics-master.com). However, the community remains rather restricted. We see the possibility of large synergistic effects when combining existing initiatives in a worldwide network. As a first step, teaching material could be made available by sharing via a common website. Then, existing training platforms and incubators could use the website as an additional outlet to advertise their offers. This would make the links between them visible to the community and could help to emphasize the local specificities. Institutes wishing to join the network and to host incubators and/or platforms would need to meet the demands of these facilities by employing a small number of permanent staff members who maintain the local infrastructure, train the visiting scientists in new techniques, and give advice for designing experiments. The benefit for the institutions would be in the long term: through the training platforms, students beginning their PhD project would be better prepared, which would enable them to make significant contributions earlier. Furthermore, it would allow the institutes hosting the incubators to identify promising young scientists at an early stage, which could eventually even lead to recruitment. Taking all these elements together, the structure of the network would support young scientists in developing interdisciplinary research programs, both in terms of developing collaborations and improving the assessment of such work. The incubators with a constant flow of scientists and a few permanent local groups would provide a supportive environment to young scientists and ease their integration in the academic environment. Participation in the network could be then viewed as a plus in a CV helping to establish new paradigms that are used to evaluate scientific achievements at early stages of a career, instead of numbers of publications and impact factors.

Through existing institutes and local programs, there is already ample experience available for organizing platforms and incubators as we have sketched above. They show, in particular, that there is no need to simultaneously be an expert biologist and physicist to provide new ideas in these interdisciplinary topics. What is needed, though, is to develop and adopt a suitable language for translating concepts from one field into another (Riveline and Kruse, 2017). To this end, simple examples that serve as an entry point into new topics would be treated in lectures. In this way, students and other visitors alike would be enabled to take new roads of research that they could never have taken without these stays. If successful, this global initiative could lead to a generation of researchers with a broader scientific culture in physics and in biology, who will be well prepared to address new challenges in understanding living matter.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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