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A CONCEPTUAL MAP FOR SOFT CONDENSED MATTER PHYSICS: A BASIC FRAMEWORK FOR MULTIDISCIPLINARY AND COOPERATIVE LEARNING

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ABSTRACT. The development of innovative teaching methods is an effective way to promote new science education standards, in view of a positive feedback of the student performance. Despite the teachers positive attitudes towards the application of innovative learning approaches, the rapid progress of science and technology in the last decades requests a renewed global approach and a synergistic organization of the educational contents for an efficient teaching of the scientific topics. Modern teaching programs request then an efficient approach which allows to clearly identify the role of each discipline within the complex organization of the novel scientific concepts. In recent years, the progress in soft condensed matter research was driven by modern methods in both the experimental techniques and the theoretical approaches. In this article, we propose a conceptual map for a multidisciplinary approach of the post-graduate programs in soft condensed matter physics, one of the most important field in modern science and technology scene. We highlight the conceptual interconnection and the synergistic relation between different sub-disciplines of the field. The proposed conceptual map may stimulate the exploration of new approaches for the integration of knowledge and skills both from the experimental and theoretical point of view. In this respect teachers can organize scientific curricula by organizing and representing knowledge conceptually, by developing a curriculum that integrates the different (experimental and theoretical) topics appropriately and by designing environments and tasks that support motivation and (interest-based) cooperative learning.

1. Introduction

The development of innovative teaching approaches and skills for an efficient way of learning the advanced concept of science increase students' interest and improves classroom environments. In this respect, The development of specific research approaches based on interdisciplinary studies and innovation investigation represents a fundamental element of modern teaching (Kaufman and Brooks 1996). The post-graduate programs of physics education, in fact, are involved in developing, implementing, and assessing research-based curricula that are profitably integrated into the various programs of the different scientific disciplines. Their goals include the improvement of students understanding of physics within the general subjects of the modern nanotechnology, through the improvement of student

attitudes toward physics applications, as well as the improvement of teacher preparation in the varied and complex world of scientific knowledge. The teaching programs request then a synergistic approach which allows to clearly identify the role of each topic within the complex organization of scientific knowledge (Summers *et al.* 2005; Stock and Burton 2011).

Herein, we propose a conceptual map for the multidisciplinary approaches to soft condensed matter physics (SCMP) in academic postgraduate programs. We shortly introduce some of the major techniques commonly used for studying soft condensed matter. Soft condensed matter materials, which include, traditional colloids (such as amphihiles, surfactant), polymers, gels, liquid crystals, emulsions, granular materials, and many biological materials (such as proteins, oligonucleotides, phospholipids), have in common that they are self-organized in nanostructured systems, *i.e.*, with structural features that are much smaller than the overall dimension of the material but much larger than the component atoms. We highlight the role of the different sub-topics of the soft condensed matter physics, by highlighting the synergistic relation and the conceptual interconnection between different parts of the field. In this respect, the development of a conceptual map may help to efficiently organise the relevant information without the constraints of the single-discipline of traditional curricula. The conceptual map may also stimulate the exploration of new solutions for a multi- and inter-disciplinary integration of knowledge (and skills) which student, at any level, are required nowadays to have.

2. Interdisciplinary and transdisciplinary academic science curricula: Toward an integrated approach

As the amount of scientific knowledge in a specific discipline increases, there is a spontaneous tendency for specialization. Topical research fields generate subfields that then become entities in themselves that promote further subdivision in further specialization. Certainly, the specialization of science gives the advantages of the greater focusing in experimental work, the establishment of specific standards and can produce organizations with their related research efficiency, specialization also carries risks of rigidity and isolation. Many scientific discoveries are made at the interfaces between different fields of science and, very often, it is possible for many disciplines to benefit from advances in different fields. In this respect, a great impetus in favouring the integration of the different disciplines can be obtained through the adoption of specific teaching programs devoted to the integration between the different academic curricula. The principal aim of an interdisciplinary (and/or trandisciplinary) approach to modern teaching is based on an effective integration of the relevant topics of the curriculum, where students can cultivate scientific inquiry through an efficient coordination of both knowledge and skills (Summers *et al.* 2005; Stock and Burton 2011). The development of the connections between different fields of scientific knowledge is one of the most important ways to shift the paradigms of each different established scientific disciplines.

An integrated approach to the multi-directional research fields of science, allows learners to study, investigate and organise the relevant information, without the constraints of the single-discipline of the traditional curricula. However, despite the intense debate present in recent years (Kaufman and Brooks 1996; Summers *et al.* 2005; Jerneck *et al.* 2011; Stock

and Burton 2011), the effective integration is still far from having reached its full objective in the different fields of science.

A modern teaching approach based on the integration of different disciplines stimulate students to discover the interrelationships between the different curricular topics, while avoiding the duplication of arguments to study (Figure 1). In this sense an integrated approach in SCMP allows the efficient development of skills around a central theme, instead of focusing on learning in isolated curriculum subjects.

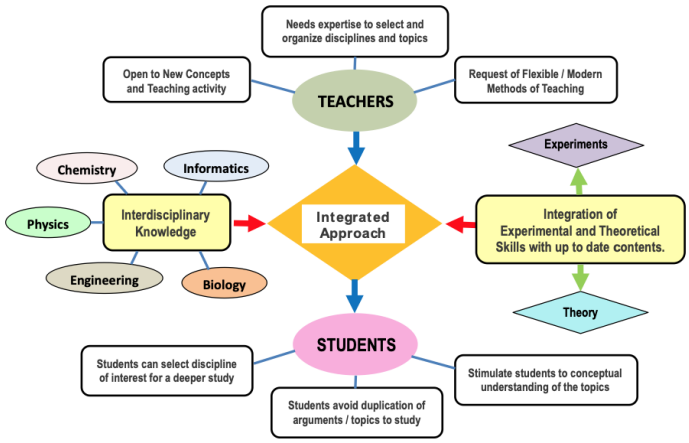

FIGURE 1. Conceptual Framework for an Interdisciplinary and Transdisciplinary Approach.

From the teachers side, the integrated approach requests modern and flexible methods of teaching and expertise (Figure 1). This needs well equipped and expert teachers who are capable of using modern methods of teaching, especially for what concerns the modern mathematical and computer approaches. A new generation of teachers should be able to systematic effort the challenge to integrate the alternative perspectives of different disciplines into a unified and coherent framework of arguments. Moreover teachers are provided with the special opportunity to work together, by increasing the collegiality, in view of the definition of flexible programs with rigorous cross-disciplinary approaches (Kaufman and Brooks 1996). One interesting mechanism for promoting interdisciplinary and transdisciplinary research is the creation of educational institutes within departments that include some topical disciplines from diverse research fields and provide the original opportunities for intense interactions outside the different specialized fields. The development of institutional criteria to recognize the contribution of individuals to team science projects should also be encouraged. Within this aim, seminars, and scientific meetings may be profitably organised and structured around individual departments or research fields.

3. Soft condensed matter physics: Basic concepts and grand challenges

As evidenced in previous sections, the integrated approaches allow the efficient development of skills around a central theme, instead of focusing on learning in isolated curriculum subjects. Various methods and strategies can be adopted to efficiently effort the programming of flexible teaching programs in the fields of modern science and technology. In this section we focus our analysis in one of the main topics of the soft condensed matter physics (SCMP).

The study of condensed matter physics in postgraduate academic programs is mainly motivated by the demand of search for novel and advanced materials with unexpected properties. This research field, which is one of the largest subfield of modern physics, seeks to understand the structural and dynamic phenomena arising from the interactions of particles ($\sim 10^{23}$ atoms, molecules or macromolecules) in simple or multicomponent macroscopic materials (Cohen and Louie 2016). This field of physic can be divided in the sub-fields of *"hard" and "soft" condensed matter physics*.

Hard condensed matter physics (HCMP) deals with materials with higher structural rigidity such as crystalline solids, glasses, insulators, metals, semiconductors and new quantum materials, with the aim to describe their structural, electronic, and transport properties arising from relevant correlations of their basic components at the macro/nano scales of the materials (Cohen and Louie 2016). *Soft condensed matter physics (SCMP)*, on the contrary, describes the macromolecular self-assembly processes and structural organization in the soft-interacting materials (Jones 2002; Hamley 2007). This important field of physics includes the study of colloidal dispersions, soft glasses, liquid crystals, polymers and polyelectrolytes, complex fluids and biological systems (such as bio-membranes and cells). These materials have a vast number of important technological applications in the cross-interdisciplinary fields of material science, biotechnology, nanomedicine, food and personal care products research (Jones 2002).

While in hard condensed matter physics the materials are typically organized on a regular crystalline lattice and it is often possible to accurately predict the material properties starting from the knowledge of the interactions between the individual atoms, the soft condensed matter systems present an intrinsically heterogeneous structure, which is characterised by a complex combination of soft interactions across different length scales, and it is much more difficult to predict their dynamical behaviour. The subtle interplay between interactions and thermal fluctuations can lead to complex emergent behaviour, such as self-assembly, spontaneous pattern formation, or a sensitive response to external stimuli (Trusso *et al.* 2011; Marchetti *et al.* 2013; Lombardo *et al.* 2019a, 2020c). It must be pointed out, however, that the differentiation of the two kinds of condensed matter physics holds at energies close to k_bT, since drastic conditions and/or use of extremely powerful sources of energy can give hard matter the possibility to destroy its strong bonds so that soft behaviour can be achieved.

Because of the large variety of nanomaterials and systems that can be classified as soft condensed matter, it can be considered as an inherently transdisciplinary field, in which various sub-fields come together including chemistry, physics, materials science, nanotechnology, engineering and biology. Due to the broad in scope of this field, it is impossible to precisely describe the entire range of outstanding issues and problems or even

to identify a precise number of key challenges. For this reason, only an highlight focused on a small selection of key challenges in the field will be introduced.

One of the main feature of soft condensed matter systems is the *self-assembly process*, that consist on a spontaneous formation process of mesoscopic structures starting from small building blocks (Domb *et al.* 1994; Glotzer and Solomon 2007; Calandra *et al.* 2015a; Lombardo *et al.* 2020b). The simplest example of the self-assembly is that of amphiphilic molecules (or surfactants) in a selective solvent. While in the low concentration region of water solution of amphiphiles, surfactants and lipids, the micelles or vesicles are the most preferred structures, with usually compartimentalizing functions even in drastic conditions (Lesieur *et al.* 2000; Kiselev *et al.* 2001a,b; Holmberg *et al.* 2002; Zana 2005; Calandra *et al.* 2011), at higher amphiphiles concentration more complex structures (such as cubic, hexagonal, lamellar, bicontinuous morphologies) can be observed (Calandra *et al.* 2000; Fong *et al.* 2012; Liveri *et al.* 2018). In the extreme situation of pure amphiphiles (in the liquid state), the typical characteristic morphology and dynamics of structured, stabilizing and glass forming liquids are observed (Calandra *et al.* 2013a, 2014; Dierking and Al-Zangana 2017; Lagerwall and Scalia 2017). Moreover, opportune mixture of different amphiphiles that can give peculiar structural properties that can trigger the arising of striking emerging properties. Those features are driven by the interplay between local molecular rearrangement and partially/selectively arrested dynamics, like 1D molecular diffusion, enhanced and/or anti-Arrhenian behavior of conductivity, and so forth (Abe 2004; Calandra *et al.* 2012, 2013b, 2015b).

More examples of complex structural and dynamic behaviour can be found by using block copolymers as building blocks (Feng *et al.* 2017). The possibility of molecular control by tuning the desired polymer composition and architecture, makes these systems a versatile tool to study, in a convenient way, the rich and complex phenomenology in the field of colloidal science and SCMP, as well as stimulates the design and engineering of advanced materials with desired properties (Mallamace *et al.* 2001; Chen *et al.* 2002; Lombardo *et al.* 2004b; Mai and Eisenberg 2012). Among these classes of systems particularly representative are amphiphilic copolymers having poly(ethyleneoxide) (PEO) as the water soluble block, due to their promising applications in the field of, material science, environment technologies and biotechnology (Alexandridis and Lindman 2000; Forster 2003; Lombardo *et al.* 2004a; Bonaccorsi *et al.* 2013a; Lombardo *et al.* 2019b).

Self-assembly also offers an alternative strategy for nanomaterials formation by means of the bottom up approach by using nanometer-sized colloidal building blocks, and by tuning the interactions by varying the surface charge, pH or salt concentration, or by adding polymeric additives, or by decorating the particles with polymers, specific ligands, or complementary DNA strands (Gale and Steed 2012). Many examples of such nanostructured systems can be seen in biotechnology, where the use of biological building blocks, such as lipids, proteins, carbohydrates and oligonucleotides (DNA, RNA) biomolecules can self-assemble into highly complex functional nanostructures such as spherical or cylindrical micelles, vesicles, fibers, ribbons, supramolecular gels, or more complex hierarchical structures (Sharma *et al.* 2018; Wang *et al.* 2019).

Within those complex self-assembly processes, a prominent role is played by water molecules and their special microenvironment. Many recent investigations evidence, in fact, the way in which biomolecular activity of water is involved in structures, stability and

dynamics of many biological systems (Franks 1982; Israelachvili and Wennerström 1996; Magazù *et al.* 2010; Varga *et al.* 2010; Disalvo 2015). Critical investigation and analyses of the water properties in biological systems emerging from the recent studies evidence, in fact, the important role of the interaction at the complex interface between the biomolecular systems (such as carbohydrates, protein and lipids bio-membranes) and water molecules, in realizing a functional structural network in which the biological systems may be considered as a complex structure stabilized by water (Disalvo *et al.* 2008; Kumar and Keyes 2012; Fenimore *et al.* 2013; Magazù *et al.* 2013; Caccamo and Magazù 2016; Magazù *et al.* 2016; Roy *et al.* 2016; Caccamo and Magazù 2017b). In this case the hydrogen bonds and hydrophobic effect play a crucial role for the establishment of the required structure-function relationship and stability within various bio-environment (Magazù *et al.* 2007; Moiset *et al.* 2014; Caccamo and Magazù 2017a; Magazù *et al.* 2018).

4. Experimental approaches for the study of SCMP

The post graduate courses of modern academic programs should provide the development of cross-interdisciplinary skills (tools and methods) to better describe the (complex) systems of SCMP. One of the main focus of this research field is to discover the relation between the microscopic structural properties and their bulk mechanical or collective behaviour of the systems. As reported in Figure 2, the main experimental methods for the investigation of the structural properties of (multicomponent) systems in SCMP are the *spectroscopic (and scattering) techniques* and the *image (microscopy) techniques*. Those techniques represent the most employed experimental approaches for a large variety of soft-materials in the interdisciplinary fields of biotechnology, nanomedicine and in material and environmental science (Volino 1978; Pawley 2006; Borsali and Pecora 2008).

Both the two main approaches use a radiation source as the interaction probe and a detection system that collect the response of the material system (Volino 1978; Pawley 2006; Borsali and Pecora 2008) resulting from the action of the stimulating probe. While the microscopy techniques furnish high spatial resolution structural pictures in real space (Pawley 2006), spectroscopy and scattering methods provides important statistical (ensemble-averaged) information of material systems in the reciprocal space (Volino 1978). The relevant wave-vectors k probed correspond to length scales ranging from few nanometers to fractions of millimetre (Berne and Pecora 1976; Glatter and Kratky 1982; Fitter *et al.* 2006; Magazù *et al.* 2011; Caccamo *et al.* 2020; Lombardo *et al.* 2020a).

On a more general background, the study of the interaction of the electromagnetic radiation with the material systems is described by a generalised *dynamic structure factor* $S(k, \omega)$ that describes the molecular motion (*i.e.*, rotations, vibrations, translations) of nanostructured molecular systems of the SCMP in terms of the scattering wavevector k, and the frequency ω of the detected radiation response (Volino 1978; Borsali and Pecora 2008).

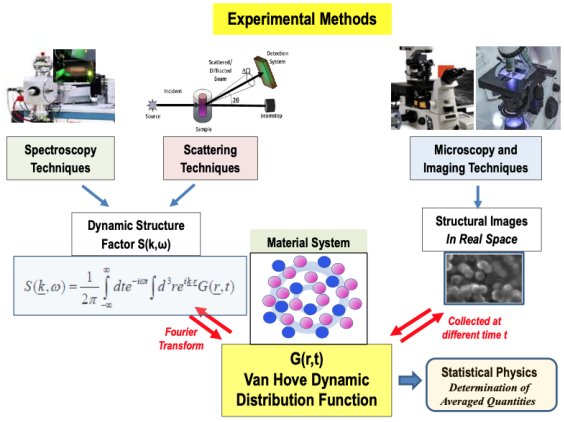

FIGURE 2. Main experimental approaches to the study of soft condensed matter physics.

For example, the dynamic structure factor $S(k,\omega)$ is probed by the inelastic neutron scattering experiments, through the measurement of the scattering differential cross section $(d^2\sigma/d\Omega d\omega) = a^2(E_f/E_i)^{1/2} \cdot S(k,\omega)$, (where E_f and E_i are the initial and final neutron energies) (Volino 1978). As reported in the conceptual map of Figure 2, the *van Hove distribution function* $G(r,t)$ plays a central role in the description of the main features of spectroscopic (and scattering) techniques (Hove 1954). This function represents a (real-space) dynamical correlation function that characterizes the space-time distributions of pairs of particles of a multicomponent system (such as a fluid or a general material system) (Calandra *et al.* 2011). It describes the probability of finding a particle at position r at time t, given that a different (or the same) particle was located at the origin $(r = 0)$ at the initial time $(t = 0)$ (Hove 1954; Fitter *et al.* 2006).

Apart the spectroscopic (and scattering) approaches, in recent years the advent of modern microscopy techniques allows to characterize with high spatial resolution the structure of many multicomponent systems of SCMP in real space (Pawley 2006). Optical measurement techniques are ubiquitous across many disciplines of science. In an optical microscopy experiment the material system of interest is illuminated with visible light and is imaged by a specific photosensitive detector. With the advent of digital imaging and large-scale digital storage, optical measurements can now easily address dynamic processes, with an enhanced spatial and temporal resolution, for the measurement of a wide range of materials typology and an efficient storage, that ensure enough experiments for well-converged statistics.

As evidenced in Figure 2, a conceptual link to those apparently unrelated techniques can be found in the definition and computation of the van Hove distribution function $G(r,t)$. The function $G(r,t)$, that summarizes the structural properties of the material system (spatial correlation of their main components), can be computed starting by the analysis of images collected in the real space (at different times). An interesting example of the computation of the function $G(r,t)$ is given by the digital fourier microscopy (DFM) approach for the study of the dynamics of soft materials (Giavazzi and Cerbino 2014).

5. Theoretical approaches for the study of SCMP

The key idea in the design and development of novel self-assembling systems is that the final nanostructure and function can be pre-programmed starting from the interaction of the individual (initial) building blocks and the initial configuration of the system. For many simple systems, the final structural properties of the self-assembly process is driven by the thermodynamic equilibrium and can be predicted by theoretical models based on free energy minimization. However, in more complex systems, for example when we are in presence of multiple species (building blocks) that interact with different forces or when various self-assembly pathways compete with one another, the free energy landscape may exhibit various (local) minima in which the self-assembling structures can become kinetically trapped. For this reason, theoretical modeling investigation is needed, together with novel approaches that can study the fine details of the specific self-assembly process, and unravel the complexity that emerges when complex combination of soft interactions (or strong interplay between kinetic pathways) come into play. Molecular dynamic (MD) simulations and analytical theories represent the main theoretical approaches for the study of multidisciplinary curriculum in SCMP.

Molecular dynamics (MD) simulations methods are able to describe a wide range of soft matter processes, addressing a variety of interdisciplinary issues including conformations of polymers and proteins, relevant bio-conjugates and material complexes (Allen and Tildesley 1989; Rapaport 2004). The MD approach is particularly important for the study of self-assembly processes of nanoparticles and their interaction with biological systems, like carbohydrates, proteins, lipid membrane and cells (Allen and Tildesley 1989; Rapaport 2004; Ferrario *et al.* 2006). As evidenced in Figure 3, the form of the inter-particles interaction plays a prominent role in determining, with its mathematical expression, the numerical solution of the molecular dynamics approach. For this reason different molecular dynamic (MD) frameworks and solution schemes has been implemented in a wide range of investigations, including full atoms or coarse grained MD, Monte Carlo or Ab initio molecular dynamic (Allen and Tildesley 1989; Rapaport 2004; Ferrario *et al.* 2006).

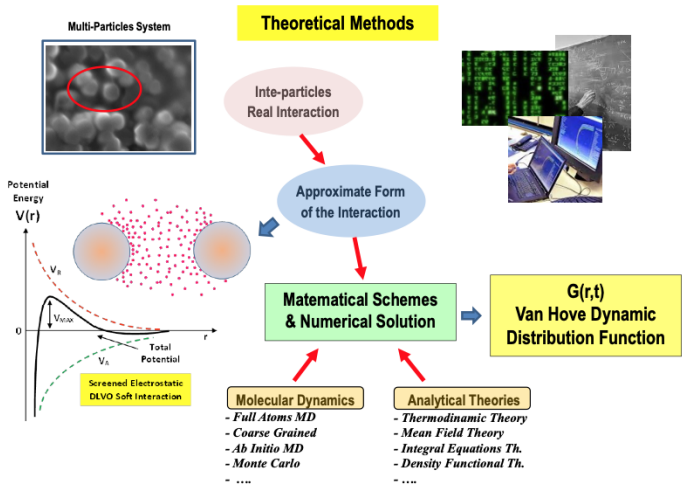

FIGURE 3. A conceptual map describing the main theoretical methods for the study of the properties of soft interacting materials.

On the other side, the use of *analytical theories* furnishes a powerful tool for a mathematical representation of complex phenomena in SCMP, by the calculation their potential observable properties (Figure 3). Together with basic thermodynamic and statistical theories, different theoretical approaches have been developed for a wide range of investigations in the different research fields of SCMP, including mean field theory (MFT), density functional theory (DFT) and integral equations theories (IET) just to name a few (Grosberg 1994; Bloom and Mouritsen 1995; Frenkel 2002). As in the case of molecular dynamic simulation, the analytical theories often request a simple mathematical form for the solution of the main relevant interactions involved. The employment of suitable numerical solution schemes allows the exploration of approximate solution of the investigated many-particle, complex systems of SCMP.

For example, in integral equations approaches the solution of the O-Z integral equation is possible only after appropriate solution schemes (so called closure relations), such as the hypernetted chain (HNC), mean spherical approximation (MSA), Percus-Yevick (P-Y) (Hansen and Mc Donald 1986; Belloni 1991). The integral equations theoretical approach has been employed to investigate the strength and range of interparticle interactions in different material systems of SCMS including amphiphiles micelles, dendrimers, lipid vesicles and proteins (Cantu *et al.* 1993; Abramo *et al.* 2012; Lombardo 2014; Lombardo *et al.* 2016, 2018).

6. Combined experimental and theoretical approach in SCMP

Future research in nanotechnology and material science will move toward the investigation of increasingly complex, supramolecular and hierarchical systems, with the aim to fabricate innovative well-defined nanomaterials that links soft matter chemistry to hard matter sciences (Bonaccorsi *et al.* 2009, 2013b; Li *et al.* 2017; Quan 2018; Pasqua *et al.*

2019). For these purposes the use of combined approaches, that associate a deep theoretical analysis in connection to the experimental investigations, will become imperative. Combined theoretical-experimental approaches has been recently applied in an increasing number of soft materials investigations with the aim to elucidate the design rules for the complex self-assembled nanostructured systems of SCMP (Olafsen 2010). For example molecular dynamics simulation techniques have been widely employed in connection with experimental methods such as X-ray crystallography (Hummer *et al.* 2004), NMR (Kapla *et al.* 2015), and small angle (X-rays and Neutron) scattering (Pan *et al.* 2014) investigations. Within these approaches the molecular interactions can be directly inferred from the best simulated molecular system.

Similarly, also the analytical theories are involved in the combined theoretical-experimental investigations of material systems of SCMP. Theoretical approaches greatly help the structural interpretation of the experimental results as well as the identification of the key properties that primarily influence the structural and dynamic properties of SCMP materials. In this respect, the direct comparison of the crucial parameters obtained from theoretical and experimental approaches request the employment of suitable mathematical models and novel computational efforts (Dill and Bromberg 2010; Magazù *et al.* 2012; Calandra 2020; Pochylski *et al.* 2020).

The ability to design new experiments and to draw hypotheses within a research investigation represents a crucial step for the scientific work of the new generation of postgraduate students and young researchers. This requests a broader interdisciplinary conceptual knowledge in connection with an integration of skills with up to date contents.

7. Connecting experiments and theory: The role of statistical physics

Statistical physics plays a central role in academic curriculum of SCMP as it allows the description of the collective behaviours of large ensembles of interacting units (building blocks). The employment of statistical physics approaches facilitated a growing understanding of fundamental processes such as the main self-assembly mechanisms underlying many advanced materials in nanoscience (Jones 2002; Porto *et al.* 2019). Moreover, statistical distribution functions (such as the van Hove function) represent the fundamental link between theoretical approaches and the main results obtained with experiments. Measurable parameters and properties obtained by experimental approaches can be obtained as averaged quantities of the relevant distribution functions (see Figure 4) and can be calculated within the framework of the different theoretical approaches. This allows to identify the number of physics concepts of interest within the multi- and inter-discilinary contests, thus providing the proper tools and skills to investigate progressively complex nano- and super-structures in the rapidly expanding field of material science and nanotechnology.

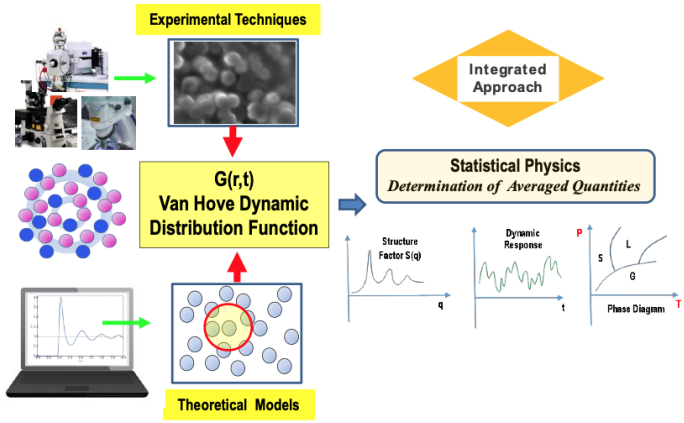

FIGURE 4. Link between experimental techniques and theoretical models. Role of statistical physics in the determination of the averaged quantities that should be compared with the measured parameters (observables) of the experiments.

Within this context, the planning of the teaching units of the different topics of SCMP requests then a suitable link to well defined topics of statistical physics. This link provides an adequate theoretical explanation of the structural properties and their connected spatial/temporal processes involved in large variety of systems, in the cross-interdisciplinary fields of biology, nanomedicine and material science. The interdisciplinary character of these topics will stimulate students to reflect on the cross-disciplinary thinking and the need for a fruitful collaboration between expertise coming from the experimental and theoretical world (Guala 2002; Coffey and Alberts 2013).

8. Supporting conceptual understanding. Multidisciplinary and cooperative learning

Cognitive science researches evidence that we learn more effectively when our minds are fully engaged, when we perceive more clearly how ideas are conceptually connected to one another, and when the tasks we encounter are motivating because they are interesting and easily accessible (Johnson and Johnson 1992; Goldman *et al.* 2016). According to those indications, the scientific curricula (in the field of SCMP), can be profitably organized according to the following steps:

1) organizing the scientific knowledge conceptually;

2) developing a curriculum that integrates the inter-disciplinary topics appropriately;

3) designing environments and tasks that support motivation and (interest-based) cooperative learning.

The student's learning process is enhanced when they have a cognitive map that explain the relationships among concepts within a scientific domain, and that reveal how their basic principles are connected with one another (Goldman *et al.* 2016). Moreover, cognitive researchers have evidenced that organizing knowledge (and skills) in schemas facilitates

retrieval and use of material from long-term memory, thus supporting a meaningful learning in complex cognitive domains (Goldman *et al.* 2016). This can be accomplished by providing explanations of central concepts and relationships at key junctures, offering useful texts, sequencing the tasks from less to more complex with instructions and information at each step. Moreover, the learning process should provide a true interdisciplinary learning platform through the development of a curriculum that appropriately integrates the different (experimental and theoretical) topics. In this respect, the conceptual map that we reported in Figure 4 could be considered an initial useful support for the study of SCMP in academic curricula. Moreover, as physicists, chemists, biologists, engineers work mostly in groups and less often as isolated investigators, similarly, students should gain experiences in sharing responsibility for learning with each other. In fact, together with the academic purpose, the teaching method should also serve to develop social and cooperative skills in the students, as recommended by educational agencies (Johnson and Johnson 1992). Within this perspective of interaction, knowledge sharing, analysis and interpretation, the *cooperative learning* approach could be considered of paramount importance for the development of the student's skills and knowledge abilities (Panitz 1997; Zakaria and Zanaton 2007). In this context, in fact, the team responsibility, communication and feedback become more effective than the usual individualistic textbook-homework-work approach. The organization in small teams (with students having different ability levels), allows the students to perform a variety of learning activities to improve their understanding of a specific topic within a collaborative environment, that stimulate students conceptual discussions, analysis of conjectures, hypotheses. Finally, modern educators should select high-quality curriculum materials that support a conceptual organization and understanding of the interconnected disciplines, thus offering thoughtful guidance for productive engagement. They should also select appropriate materials for the useful representations of concepts/ideas, and suitable means to connect them to students' experiences.

9. Conclusion

The rapid progress of nanoscience and nanotechnology experienced in the last decades has changed the objectives and the way of teaching scientific disciplines. In the last decades, much of the scientific research and technological investigation work is mainly concerned with the understanding of the structure-function relationship at the nanometre size scale of novel material systems. Modern global approaches within science university curricula request a synergistic organization of both knowledge and skills for an efficient integration of the relevant information of the different involved topics. Efforts to remove barriers to interaction between scientific disciplines are likely to yield substantial benefits in the future. Mechanisms to reduce isolation can include inviting speakers from other fields to specialized meetings, encouraging cross-field exchanges of research experiences, and an active support research project of interface research. In this perspective, we propose a conceptual map for the multidisciplinary approaches of soft condensed matter physics in academic postgraduate programs. We point out the role of the main approaches of the soft condensed matter physics by highlighting their relation and their conceptual interconnections. A central role is given by the statistical physiscs, as the study of the statistical distribution functions allows a useful connection between theory and experiments. Within this contest teachers

need adequate preparation in both content and instructional strategies in order to face the challenges for a multi- and inter-disciplinary integration of knowledge in science. They can organize scientific curricula by organizing and representing knowledge conceptually, and by developing a curriculum that integrates the different (experimental and theoretical) topics in an appropriate way, within an efficient cooperative learning environment. In few words, a new generation of teachers that are able to systematic effort the integration of the different disciplines into a unified and coherent framework of arguments.

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