Multidisciplinary Education: About Some Aspects of Teaching Biophysics

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The European Conference on Education 2023
Official Conference Proceedings

Abstract
This article presents one of the most pressing issues for undergraduate educational programs - interdisciplinary education. An interdisciplinary subject requires careful consideration of new issues and concepts in different contexts, identifying relationships between subjects, and developing common aspects, which is quite difficult to effectively implement within one discipline. This article discusses the problems and prospects associated with the teaching of biophysics. The main emphasis in the work is on the movement of blood in thin capillaries, the study of which is associated with microrheology. Various models have been proposed to explain the rheological properties of blood. These models, considered in the example of dispersed (two-phase) systems, describe the blood flow in capillaries only quantitatively, but the features of erythrocyte mobility in small capillaries within the framework of these models remain unclear. The laws of hydrodynamics or rheology alone cannot explain these features. To improve these models, we suggest that students consider the electrical properties of the dispersion system. This article considers the concept of blood cells and corpuscular elements functioning as electrical systems. These complex electrical systems are constantly moving in vessels of different diameters and, of course, are sensitive to changes in various hydrodynamic influences. Students are allowed to independently carry out practical work on these models, changing various indicators of blood. Unfortunately, microrheology and related issues are little discussed in textbooks. However, students must be familiar with the current problems, difficulties, and still scientifically inexplicable questions in this direction.

Keywords: Multidisciplinary Education, Interdisciplinary Approach, Biophysics, Microrheology, Dispersed System

Introduction

It is unquestionable that all academic degree programs provide for the teaching of interdisciplinary subjects (Medicine, 2023). In the era of modern high technologies, it is necessary to introduce high-quality innovations in the educational process. Today it is not enough to rely on traditional methods to obtain the necessary knowledge - in an environment that is changing at an amazing speed, it is necessary to conduct the learning process based on innovative approaches. The teacher of each subject should arouse in the student a greater interest in the study of a subject, transfer to him not only the theoretical and practical knowledge accumulated in this area and acquaint him with modern achievements, but also focus on the prospects available here, modern research, i.e., to speak, "to see more" in his subject than it might seem at first glance (Dotsinsky, 2010).

This article discusses the problems and prospects associated with the teaching of biophysics. This applies to teaching the movement of blood in thin capillaries, the study of which is associated with microrheology (Kalandadze et al., 2022). To teach this subject matter effectively, one must possess extensive knowledge of the latest advancements in medicine, physics, biology, chemistry, and rheology. However, this can prove to be challenging in today's era of advanced technology (Figure 1).

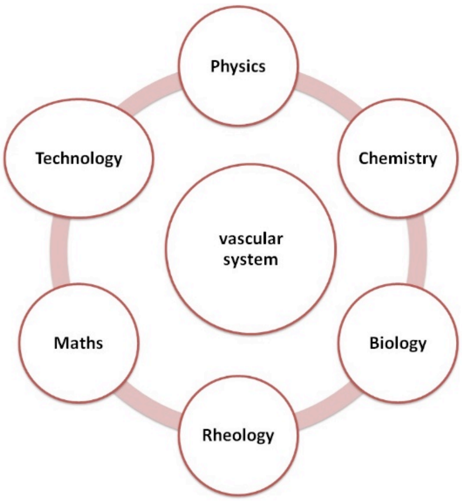

Figure 1: Vascular system is a multidisciplinary topic of biophysics

A textbook written by a group of doctors clearly suffers from a lack of use of the skills, achievements, and logical reasoning of the exact sciences. Accordingly, there is an incomplete physical, chemical and mathematical analysis of the pathological course of certain diseases, such as cardiovascular, microrheological, and other processes (Kalandadze, 2022).

We will discuss how interdisciplinary approaches in the learning process can be based on the formation of ideas between the integrity of knowledge and the different scientific fields. We will also explore how researching and analyzing the connections between subjects can help us understand the rheological properties of blood.

In the process of discussing some issues, it is also necessary to use a popular approach to the problem, which will help the student understand the material.

Let us recall the famous public speech of the American physicist Feynman in 1959 (Feynman, 2011). This is a good example of how important it is to convey complex topics in a popular speech to an audience. Especially those if a topic has a multidisciplinary level.

The main emphasis in the work is on the movement of blood in thin capillaries, the study of which is associated with microrheology. The features and approaches to the study of the physical laws of this issue are discussed. Microrheology and related issues are little discussed in textbooks (Glase, 2012). However, it is necessary that students be familiar with the challenges, difficulties and still scientifically unexplained issues in this direction that are relevant today. Knowledge of their physical foundations will greatly advance medical education, both in terms of practical use and from a scientific point of view.

Methodology

For students to better understand and perceive the depth of the material being explained and the difficulties associated with it, it is essential to divide the topic into multiple segments based on its level of complexity. The first part is explained and justified on a scientific level; the second part contains unsubstantiated assumptions about the events in question; then a joint discussion of possible hypotheses and approaches based on current existing research and, finally, forecasting the prospects of the issue. This is not easy, because the teacher must know the basic laws and patterns of subject disciplines.

In biophysics, the study of the flow of blood in the vascular system should begin with large vessels and end with a consideration of its movement in the capillaries (see Figure 2).

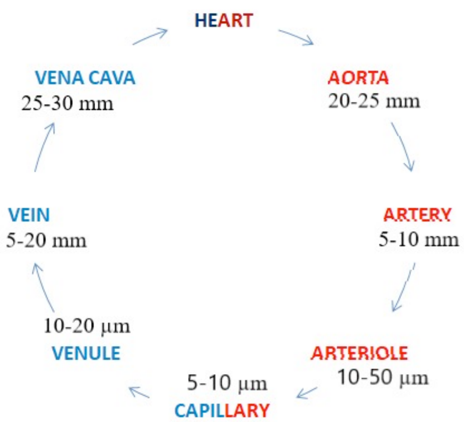

Figure 2: The diameter of blood vessels in the vascular system

First, it is necessary to consider the basic hydrodynamic equations underlying hemodynamics. With their help, the flow of blood in a large vascular system is explained (Pollock et al., 2023). After that, the movement of blood in the capillaries should be taken into account. The study of the movement of blood in capillaries is associated with the microrheological properties of blood (Vahidkhah et al., 2016). Explaining this aspect of the topic requires both knowledge and the skill of effective communication. The laws and regularities of natural sciences alone are insufficient to fully elucidate the processes occurring in this area.

The flow of blood within the cardiovascular system has certain distinguishing characteristics (Farina et al., 2021):

1. Fareus effect - dependence of hematocrit on vessel diameter;
2. the existence of a parietal (erythrocyte-free) plasma layer near the vessel wall;
3. obtuse (compared to the Poiseuille flow profile) profile speed;
4. the Fareus–Lindqvist effect is a clear dependence of blood viscosity on the diameter of a blood vessel.

When trying to understand the problem, students need to keep in mind that the model of viscous incompressible blood is suitable for large blood vessels (with a diameter of over 300 µm), while the flow of blood in small capillaries (with a diameter of less than 300 µm) requires consideration of abnormal properties related to microrheology (Koohyar et al., 2016).

Is it a myth or reality that the cardiovascular system defies the laws of physics? Using this phrase can be a helpful way to engage students in learning about the topic.

Results

The field of hemodynamics holds great significance in the domains of medicine and biomedical engineering. Its knowledge is vital for the development of innovative implantable devices and to comprehend the functioning of different diseases linked with blood circulation (Trejo-Soto et al., 2022).

The characteristics of blood flow in small arteries are of great interest in biomedical engineering. The results of such studies provide information that is useful in understanding in vivo blood flow conditions, in designing medical devices (e.g., organs on a chip), or in the development of more effective diagnostic tools. Although the blood flow in large arteries has been extensively studied (Nader et al., 2016) little work has been done regarding the blood flow in smaller vessels, mainly because both in vivo and in vitro experiments in arterioles and capillaries are difficult to perform.

There has been a recent increase in research on the microcirculation of red blood cells in small capillaries. Several models have been proposed to explain the rheological properties of blood in this context. However, these models only provide quantitative descriptions of blood flow in capillaries as dispersed (two-phase) systems. They do not explain the qualitative aspect of erythrocyte mobility in small capillaries (Guckenberger et al., 2017).

This study aims to provide students and physicians with a methodology that could be applied to the prediction of the overall pressure drop (ΔP) and flow characteristics across blood microvessels. This methodology involves three steps:

First, estimate the vessel diameter (see Figure 2);

Next, it is important to examine the blood velocity profile in microvessels (as shown in Figure 3) to determine the suitability of hydrodynamic formulas. When dealing with microvessels larger than 200 µm in diameter, it can be presumed that blood behaves as a consistent and uniform fluid. However, this assumption does not hold true for microvessels smaller than 200 µm, where the motion of individual red blood cells becomes significant. In such cases, blood should not be regarded as a homogeneous liquid, but rather as a cell suspension.

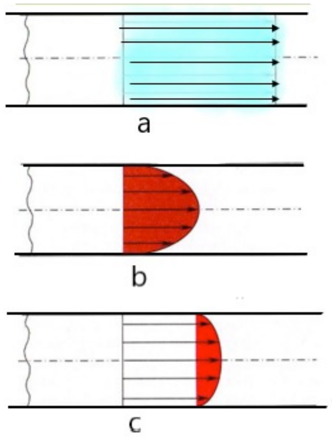

Figure 3: a) Velocity profile of an ideal liquid; b) Velocity profile of a real (Newtonian) liquid; c) Velocity profile of a non-Newtonian liquid

Blood is a complex system with unique properties. One such property is the Fareus-Lindqvist effect, which differs from the Newtonian and structural viscosity effects. In a non-uniform Newtonian fluid, viscosity increases as the diameter of the tube decreases, as per Poiseuille's law. However, for blood, a non-uniform non-Newtonian fluid, the opposite occurs. As the radius of capillaries decreases below 150 microns, blood viscosity decreases, facilitating its movement through the bloodstream's capillaries. It should be noted that the study of the properties of blood circulation revealed a number of features that distinguishes it from both Newtonian and non-Newtonian fluids. The laws of hydrodynamics or rheology alone cannot explain those peculiarities (Stergiou et al., 2019).

When studying blood movement in small capillaries, there are multiple methods available. Depending on their level of education (bachelor's, master's, or doctoral), a student may have the freedom to interpret the microrheological properties of blood in narrow capillaries as part of their research. One potential method is representing the corpuscular elements of blood as an electrical system. These systems are constantly in motion within blood vessels of varying sizes and are sensitive to hydrodynamic influences (see Figure 4).

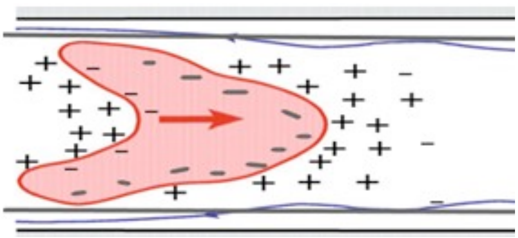

Figure 4: Deformed erythrocyte in a small capillary

Finally, the issue under discussion makes it possible to generalize the existing two-phase model (Sharan et al., 2001) using electrical parameters and conduct numerical experiments to study the microrheological properties of blood.

Conclusion

This article discusses the problems and prospects associated with the teaching of biophysics. The main focus of the work is on the movement of blood in thin capillaries, the study of which requires a thorough consideration of new issues and concepts in different contexts. The approach discussed in the article will help students to better understand the microrheological properties of blood and outline further prospects for this issue. It is important because identifying connections between different subjects and developing shared perspectives is a complex task that is not easily accomplished within a single discipline.

Additionally, we expect that the specific examples offered and described in this article will help those involved in the teaching of biophysics gain a clearer understanding of the various processes that need to be taken into account.

We hope that we have captured the reader's attention and demonstrated the need for an interdisciplinary methodology for teaching the microrheological properties of blood.

Acknowledgments

Financial support for the work was provided by Batumi Shota Rustaveli State University.

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