# UNDERSTANDING OF CARDIOVASCULAR PHENOMENA IN MEDICAL STUDENTS

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**Background:** Undergraduate (UG) medical students of II Semester of different institutions were surveyed to determine the prevalence of 13 different misconceptions (conceptual difficulties) about cardiovascular physiology. The prevalence of these misconceptions ranged from 75.60% to 25.30%. **Methods:** A list of questionnaire was selected that were diagnostic for difficulties that can seriously interfere with students mastery of the topic. Diagnostic questions were generally of the form: 'If x increases, then will y increases/decrease/show no change'. **Results:** The result suggests that students have a number of underlying conceptual difficulties about cardio-vascular phenomena. Our possible source of some misconceptions is the students' inability to apply simple general models to specific cardiovascular phenomena. **Conclusion:** UG students may 'understand' less than they appear to 'know'. Some implications of these results for teachers of physiology and medicine are explained.

**Keywords:** Cardiovascular System, Diagnostic Questions, Undergraduate Teaching

## INTRODUCTION

Students of science faculty come into classroom with preconceptions or alternative conceptions about subject matter. These preconceptions or misconceptions interfere with the learning process.

As teachers we become aware of existence of these misconceptions when we ask a student a question, receive an answer, and then reflect on the possible implications of that answer. Such questions can diagnose the existence of conceptual or reasoning difficulties, and the students' incorrect answer thus serves as diagnostic signs of those difficulties. Students' answers suggest that there are some conceptual difficulties causing the wrong answer. To determine what underlying conceptual difficulty is present, we ask additional questions to get the students to elaborate on their thinking. It is not uncommon to find that even a follow-up question to a correct answer reveals that students have significant difficult thinking about the issue at hand (i.e., the questions was answered correct but for the wrong reasons).

Misconceptions (conceptual difficulties) have been studied extensively in physics but less so in Chemistry and Biology.[1–4] Mintzes *et al* have examined the differences that are present in students' understanding of circulatory system at different educational levels (4$^{th}$ grade to college) and observed that some alternative conceptions are quite resistance to change, whereas others become much less prevalent in older people.[5]

In our present study, we determined the prevalence of misunderstanding about certain concepts related to the cardiovascular system in undergraduate medical students. We identified the underlying conceptual difficulties associated with misunderstandings by collecting written explanations of their reasoning through the use of multiple choice follow up questions, we also hypothesized that at least some conceptual difficulties in understanding CVS physiology arise from students' inability to reason about simple physical and chemical systems. Our results offer some support for this hypothesis and suggest further experiments to explore this idea.

## MATERIAL AND METHODS

A questionnaire was constructed with students' examination results class interaction, in which student found difficulty. We specifically selected questions that were diagnostic for difficulties that can seriously interfere with students' mastery of the topic. Diagnostic questions were generally of the form: 'If x increases, then will y increases/decrease/ show no change?'

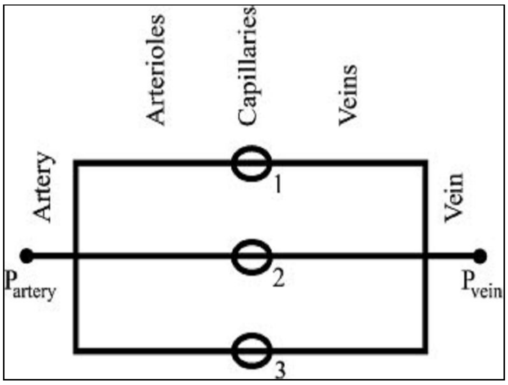
Table–1 contains the 13 diagnostic questions (DQ) used in this study. For each question, we have indicated some possible underlying difficulties for which the questions might be diagnostic solely on the basis of an analysis of the physiology involved.

We also wrote questions (GMQ 1–3, Table-2) that tested the students' ability to reason about three different general models: pressure/flow/resistance, elastic structures, and mass balance.[6] Each question described a relatively simple, non-physiological system. For each of the general model questions, there was a matched cardiovascular diagnostic question. (CVQ 1–3, Table-1) that required application of the general principal of specific cardiovascular phenomenon.

A total of 332 students participated in this questionnaire pattern after they where explained about this Performa.

## Table-1: Cardiovascular diagnostic questions and the conceptual difficulties they point to (*indicates correct prediction)

**(CVDQ1) Vasoconstriction and downstream pressure:**




Consider the small piece of the circulation shown above. The pressure gradient across the circulation ($P_{artery}$–$P_{vein}$) is constant. If the arterioles in path 1 CONSTRICT (get smaller in diameter), then pressure in the venules of path 1 will:
a) Increase b) Decrease* c) no change

**(CVDQ2) Haemorrhage and venous pressure**
A large vein in the leg of an accident victim is cut; the victim loses 2 litres of blood. The pressure in her veins will:
a) Increase b) Decrease* c) remain unchanged
*Diagnostic for elastic structure general model.*

**(CVDQ3) Decreased metabolism and venous $O_2$ content**
Arterial blood flows through an organ of the body at a constant rate. if the metabolic activity of' that organ is decreased, the amount of oxygen in each mm. of blood leaving the organ in the vein will :
a) increase* b) decrease c) remain unchanged
*Diagnostic for mass balance general model*

**(CVDQ4) Cardiac output and resistance**
If cardiac output (the volume/min ejected from the heart) increases significantly, then the resistance of the arterioles will:
a. immediately and directly increase significantly
b. immediately and directly decrease significantly
c. nut change directly to any significant extent*
*Diagnostic for determinants of vessel resistance*

**(CVDQ5) Atrial and ventricular contraction**
The ventricle fills:
a. ONLY when the atrium contracts
b. ONLY when the pressure in the ventricle is less than the pressure in the atrium*
c. ONLY when the papillary muscles contract and open the A-V valve
*Diagnostic for structure/function relationships of valves in heart; cardiac cycle*

**(CVDQ6) R and L ventricular output**
When the heart beats:
a) The right and left ventricles pump the same volume of blood each beat*
b) Right ventricle pumps less blood each beat than dues the left ventricle
c) The right ventricle pumps more blood each beat than does the left ventricle
*Diagnostic for circulation is closed circular system; Frank-Starling*

**(CVDQ7) Cap and arteriolar pressures**
The blood pressure in the capillaries is ________ than the blood pressure in the arterioles.
a) greater than b) less than* c) same
*Diagnostic for structure of circulation, pressure/flow/ resistance*

**(CVDQ8) Denervate Heart**
If all of the nerves innervating the heart are cut, the heart will:
a) stop beating
b) continue betting at the same rate
c) continue beating but at a different rate*
*Diagnostic for function (properties of) SA node, function of innervation of heart*

**(CVDQ9) Timing of R and L ventricular contraction**
The left vertical contracts NOW. The right ventricle contracts _____ the left ventricle did:
a) before b) after c) at the same time as*
*Diagnostic for structure/fluid ion of cardiac conduction system*

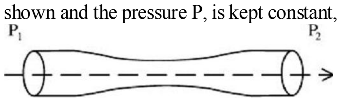
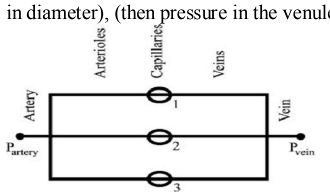
**(CVDQ10) Map is regulated variable**
The cardiovascular system holds ____ essentially constant:
a) mean arterial pressure*
b) mean arterial pressure and cardiac output
c) mean arterial pressure, cardiac output, and heart rate
*Diagnostic for control general model*

**(CVDQ11) Venous return and venous volume**
The rate at which blood is pumped out of the veins by the heart is increased. If the rate at which blood enters the veins is maintained constant, the volume of blood in the veins will:
a) increase b) decrease* c) remain the same.
*Diagnostic for reservoir general model*

**(CVDQI2) Flow in pulmonary and systemic circulations**
The flow (ml/mm) through the pulmonary circulation is ____ the flow through the systemic circulation (the rest of the body):
a) the same as* b) greater than c) less than
*Diagnostic for structure of circulation, Frank-Starling*

**(CVDQ13) Cardiac output/stroke volume**
You measure Mr. X's cardiac output and determine that it is increased above its normal value. This MUST mean that stroke volume has:
a) increased b) decreased c) no change
d) cannot be determined from the data given*
*Diagnostic for implications (qualitative) of multiplicative relationship defining CO*

**Table-2: Matched general model and cardiovascular diagnostic questions (*indicates correct answer)**

| | General Model Question | Physiology Question |
|---|---|---|
| Pressure/flow/ resistance | **(GMDQI)** A fluid is flowing through the tube shown below in the direction of the dashed arrow. If the tube is pinched as shown and the pressure P, is kept constant, the pressure P2 will:   a. increase<br>b. decrease*<br>c. remain unchanged | **(CVDQJ)** Consider the small piece of the circulation shown to the right. The pressure gradient across the circulation is constant, If the arterioles in path 1 CONSTRICT (get smaller in diameter), (then pressure in the venules of path 1 will:   a. increase<br>b. decrease*<br>c. not change |
| Elastic Structures | **(GMDQ2)** You blow up a balloon so that it has a volume of V1. Two minutes later, you take the same balloon and inflate it to a larger volume V, The pressure inside the balloon is now (at volume V) ___ the pressure that was present initially (at volume V1).<br>a. higher than*<br>b. lower than<br>c. the same as | **CVDQ2)** A large vein in the leg of an accident victim is cut, and the individual loses 2 litres of blood. The pressure in her veins will:<br>a. increase<br>b. decrease*<br>c. remain unchanged |
| Mass Balance | **(GMDQ3)** You have 5 fish in an aquarium. Water containing a certain amount of food per ml is entering the tank. Water is leaving the tank at the same rate that it enters it so the level of water in the tank is constant, if you add 5 more fish to the tank and the flow of water into the tank remains constant, then the rate at which food is leaving the tank will:<br>a. increase<br>b. decrease*<br>c. remain the same | **(CVDQ3)** Arterial blood flows through an organ of the body at a constant rate. If the metabolic activity of that organ is decreased, the amount of oxygen in each ml of blood leaving the organ in the vein will:<br>a. increase*<br>b. decrease<br>c. remain unchanged |

## RESULTS

### Prevalence of cardiovascular diagnostic signs

Table-3 shows prevalence for each diagnostic question (i) the percentage of each student population studied that did not answer correctly, (ii) the percentage of the total population (all institutions and courses) that had answered incorrectly or had conceptual difficulty with the question, and (iii) the mean prevalence and standard deviation for all of the courses.

The prevalence of particular cardiovascular diagnostic signs varied considerably; the most prevalent difficulty (CVQ4) was exhibited by 75.60% of the students studied, whereas the least common (CVQ5) was exhibited by 25.30%. The prevalence of any particular diagnostic sign tended to be consistent across the individual student populations; the largest standard deviation was 16.47% for CVQ.

### What are the underlying difficulties that lead to the diagnostic signs we obtained?

For each question, we looked for patterns in the explanations offered for both wrong answers (diagnostic signs) and correct answers. Some typical explanations are presented here.

Question–CVQ, (Table-1) asked students about the change in pressure, if any, which occurs down stream of a vasoconstriction. Pressure in the venules will decrease because the added resistance will increase the pressure drop that occurs.

Students who predicted that pressure would be increased exhibited considerable confusion about pressure how velocity and blood volume in a segment of the circulation and how they relate to the concept of resistance. On the other hand, students who predicted that pressure down stream would not change argued that altering one segment of the circulation would not affect other segment (they thought they are independent of one another). Both groups of students frequently found if difficult to incorporate into their problem solving the fact that Pa-Pv pressure gradient was stated to be constant across the vascular bed.

Explanations offered by students who correctly predicted that the down stream pressure would decrease commonly revealed incorrect thinking about hemodynamics. Despite their correct prediction, these students were often confused about the relationships among flow, flow velocity, resistance and blood volume. Some explanations of the correct prediction presented ideas that were simply irrelevant.

CVQ4, asked students to predict the immediate and direct (no via a reflex) effect on arteriolar resistance of an increase in cardiac output. There is essentially no change in resistance. Arteriolar compliance is relatively low and the change in volume that occurs is small. Thus there is an insignificant change in the radius of the vessel (which is more importantly determined by sympathetic inputs and the concentration of local tissue metabolites).

Students who predicted either increase or decrease in resistance commonly explained their predictions either by asserting that flow and/or pressure are direct determinant of vessel resistance, or they invoked some sort of regulatory response (i.e., reflex) to the change in cardiac output, even though the questions explicitly stated that reflexes were not involved in the response to be thought about.

Although many students who predicted no immediate, direct change in resistance correctly identifies the determinants of resistance (length, viscosity, radius), others were unable to generate a coherent explanation.

CVQ6 asked students to compare the volume pumped by right and left ventricles with each beat. The volumes pumped by the two sides of the heart are the same; the output of the right ventricle fills the left ventricles and output of left ventricles ultimately fills the right-ventricle. If the output is not identical, a change in filling will result that will make the two outputs equal of the 30% students who predicted that the output of the left ventricle was greater than the output of the right ventricle, and explained this by noting that the left ventricle is bigger than the right ventricle. Some students explained their prediction by nothing that the left heart output has to supply blood to the whole body (thus requiring a larger output) whereas the right ventricle output supplies blood only to the lungs.

CVQ8 asked students to predict whether dennervating the heart would cause the heart to stop beating, continue at the same rate, or continue beating at a different rate. The heart would beat at a different, faster rate. The spontaneous firing rate of the SA node is higher than the resting heart rate, which is normally slowed by parasympathetic inputs. Those students who said that the heart would stop beating quite commonly explained this by stating that the heart is like skeletal muscle and requires a neural input for contraction to occur. Among those who predicted that the rate would stay the same, most invoked the autorhythmicity of the heart (which is, of course, present) and claimed that its beat was therefore independent of nervous system (not true).

Those students who knew that the rate would change generally had quite spurious arguments to explain this. Many commented on 'pacemaker', and several indicated that nervous system modulated the spontaneous (autorhythmic) heart rate. However, none of the respondents knew that the spontaneous rate of the SA node was higher than the resting heart rate in a normal individual, even it they did know that denervating the heart somehow changes its rate.

**General model—Cardiovascular misconception relationship:**

To determine whether the inability to use a general model could give rise to a cardiovascular diagnostic sign (incorrect answer on a diagnostic question), three pairs of questions were prepared. The first question in each pair (GMDQ1–3) tested the students' ability to apply a general model to a simple non physiological system.

The second set of paired questions (CVDQ1–3) required the application of the same general model to a specific cardio vascular situation. Table-2 contains the 3 pairs of questions. Individual student performance on each question in each of the three pairs of questions was determined. We could therefore, determine whether students answering the general model questions correctly were more or less likely to answer the matched physiology question correctly. From these numbers, we calculated the percentage of students who answered both the general model and the physiology question correctly.

Table-4 contains result of this analysis. The $\chi^2$ test with computed expected values[9] was performed on these data, the results are reported below.

For the pressure/flow matched questions (GMDQ1 and CVDQ1) 41.66% of students who answered the general model question correctly answered the cardiovascular diagnostic question correctly, whereas only 29.91% of the students who missed the general model question could correctly answer the physiology question. The difference in performance on the follow-up CVQ as a function of being able to correctly apply the general model was significant ($p$=0.5).

For the elastic structure questions (GMQ2 and VDG2), the percentage of students answering CVDQ2 correctly was same for those answering GMDQ2 correctly or incorrectly (47.88% vs 54.70%), this difference was not significant ($p$>0.05).

For the mass balance questions (GMDQ3 and CVDQ3) a correct answer on the general model question was associated with a greater likelihood that the answer to CVQ3 was correct ($p$<0.001).

**Table-3: Prevalence of Cardiovascular Diagnostic Signs. (Incorrect answers to $CVDQ_3$)**

| | Course I | Course II | Course III | Total Population | Mean±SD |
|---|---|---|---|---|---|
| **DQ1** | 67.74% | 56.98% | 71.52% | 58.43% | 65.41%±7.54% |
| **DQ2** | 50% | 41.86% | 62.50% | 47.29% | 51.45%±10.39% |
| **DQ3** | 27.42% | 24.42% | 40.97% | 29.21% | 30.93%±8.81% |
| **DQ4** | 82.26% | 81.40% | 90.20% | 75.60% | 84.62%±4.85% |
| **DQ5** | 30.65% | 13.00% | 37.50% | 25.30% | 27.05%±12.64% |
| **DQ6** | 32.56% | 34.88% | 45.83% | 34.94% | 37.76%±07.04% |
| **DQ7** | 46.77% | 38.37% | 52.08% | 41.26% | 45.74%±06.91% |
| **DQ8** | 54.83% | 23.26% | 47.22% | 36.74% | 41.77%±16.47% |
| **DQ9** | 70.96% | 51.16% | 44.44% | 45.78% | 55.52%±13.78% |
| **DQ10** | 43.55% | 53.49% | 59.02% | 47.59% | 52.02%±7.83% |
| **DQ11** | 51.61% | 45.35% | 57.63% | 46.38% | 51.53%±6.05% |
| **DQ12** | 58.06% | 65.12% | 59.72% | 53.61% | 60.96%±3.69% |
| **DQ13** | 29.03% | 48.83% | 60.14% | 44.27% | 46.09%±15.86% |
| **DQ14** | 91.93% | 74.42% | 85.41% | 73.49% | 83.92%±8.84% |
| **DQ15** | 98.38% | 83.72% | 63.88% | 67.77% | 81.99%±17.31% |
| **DQ16** | 38.70% | 27.91% | 51.38% | 36.74% | 39.33%±11.74% |

Course I= 1st MBBS students Kota, Course II= 2nd MBBS Students Kota, Course III= 1st MBBS students Mullana.

**Table-4: Interaction between performance on general model (GM) question and cardiovascular diagnostic question (CVDQ)**

| | $CVDQ_1$ Correct | $CVDQ_1$ Wrong | % getting CVDQ correct | *p*-value |
|---|---|---|---|---|
| **$GM_1$ Correct** | 20 | 28 | 41.66% | $p$=0.5581 (NS) |
| **$GM_1$ Wrong** | 70 | 164 | 29.91% | |
| | **$CVDQ_2$ Correct** | **$CVDQ_2$ Wrong** | **% getting CVDQ correct** | |
| **$GM_2$ Correct** | 37 | 34 | 52.11% | $p$=0.1590 (NS) |
| **$GM_2$ Wrong** | 101 | 122 | 45.29% | |
| | **$CVDQ_3$ Correct** | **$CVDQ_3$ Wrong** | **% getting CVDQ correct** | |
| **$GM_3$ Correct** | 122 | 39 | 75.77% | $p$=0.00005 (Highly Significant) |
| **$GM_3$ Wrong** | 65 | 56 | 53.71% | |

## DISCUSSION

### Prevalence of cardiovascular diagnostic signs

The prevalence of the cardiovascular misunderstandings surveyed varied from 25.30–75.60% a range that is only slightly greater than the range of prevalence of previous surveys.

The least prevalent cardiovascular diagnostic sign (Atrial and Ventricular contraction) deals with a phenomenon about which knowledge is quite widespread regardless of formal studies in physiology. On the other hand the most prevalent misunderstanding about cardiovascular physiology (Cardiovascular output and resistance) deals with concepts from hemodynamics a subject that students at all educational levels find particularly challenging.

### What are the difficulties that impact students' understanding of cardiovascular physiology?

The answers to pairs of matched questions suggest that students who can apply general models to their understanding of cardiovascular phenomena are more likely to be able to correctly answer a related cardiovascular question. For two of the three pairs of questions, answering the general model diagnostic questions correctly was associated with a greater likelihood that the cardiovascular diagnostic questions would be answered correctly.

These results offer support to our hypothesis that some conceptual difficulties in cardiovascular physiology arises from the students inability to apply certain general models to specific physiological situations. If, as we suspect, a significant number of physiology misconceptions are the product of an inability to transfer and apply general models, it will strengthen the argument that improving students' understanding of and ability to use these models can have widespread positive effects on learning this material.

There is another source of difficulty that affects our students' understanding of important concepts in cardiovascular physiology. Some of the misconception questions appear to be nothing more than statements of facts about cardiovascular system. For example, CVDQ9 deals with the 'fact' that the right and left ventricle contract at essentially the same time. One can argue that a wrong answer to this question merely tells us that students do not know this fact. Even if this is the case, it is both surprising and troubling for both the students and teachers.

We might expect that textbook would address this topic in a way that would help out students understand this phenomenon. However an examination of four popular UG and advanced physiology textbooks reveals that three of them never state that right and left ventricles contract at the same time, and the fourth textbook states it, but in a way that could be easily overlooked by the reader.

How then would we expect students to eventually understand that the right and left heart contract together? It would be possible for students to infer or deduce this from an understanding of the structure and function of the cardiac conduction system (topics that are extensively covered in all the textbooks) but it seems likely that most students will be unable to make this inference.

**What are the implications of these results for teachers of physiology?**

First, UG students find many cardiovascular concepts difficult to understand and prevalence of these difficulties is surprisingly uniform across diverse student populations. It is possible that this prevalence is independent of how advanced the students are in their academic careers. As teachers it is essential that we know what our students find hard to understand if we are to succeed in helping them learn. This study represents the beginning of an attempt to undercover these difficulties in a systemic, broad based way. In the classroom we must be aware of these conceptual difficulties and find ways to probe our students' understanding of these concepts.

Second, UG students may 'understand' less than they appear to 'know'. Even when they are able to answer a question correctly, their ability to explain their answer may be limited to suggest that they have guessed or memorised a fact about the phenomenon in question, but have not developed a robust understanding of that phenomenon. We need to probe our students' understanding of important physiological phenomena, below the superficial level to determine whether our students truly understand what we think they understand. This can best be accomplished in a learning environment in which students are constantly testing their mental models through interactions with one another and with the teacher.[7] We also need to use formal assessment tools (multiple choice, short answer or essay questions, etc.) that measure conceptual understanding, not just memorised information.

Third, one source of conceptual difficulty about many phenomenon is the students' lack of understanding of simple general models[6] or inability to recognize that these models apply to the topic under consideration. We as teachers, need to think about general models and organise our teaching to take advantage of the power that this approach provides. This is not something to be done in a single lecture, but something that must be revisited as each new topic arises. Furthermore opportunities to practice recognising and applying these ideas.

Fourth, another source of conceptual difficulty for students is our failure as teachers and textbook writers to appreciate the difficulty that students have integrating knowledge drawn from many disciplines (Physics, Chemistry, Biology) and many levels of organisation (molecular, cellular) into a robust understanding of physiology concept. Students need help with such integration. If that help is not provided in the textbook students read or in classroom, then their understanding may stay at the level of memorised information and never achieve meaningful learning.

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