Students’ conceptions of underlying principles in medical physiology: an interview study of medical students’ understanding in a PBL curriculum

Anna Fyrenius,1,2 Charlotte Silén,1 and Staffan Wirell3

1Centre for Educational Development and Research, 2Unit for Clinical Physiology, and 3Unit for Radiology, Department of Medicine and Care, Faculty of Health Sciences, Linköping University, Linköping, Sweden

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Fyrenius A, Silén C, Wirell S. Students’ conceptions of underlying principles in medical physiology: an interview study of medical students’ understanding in a PBL curriculum. Adv Physiol Educ 31: 364–369, 2007; doi:10.1152/advan.00108.2006.—Medical physiology is known to be a complex area where students develop significant errors in conceptual understanding. Students’ knowledge is often bound to situational descriptions rather than underlying principles. This study explores how medical students discern and process underlying principles in physiology. In-depth interviews, where students elaborated on principles related to blood pressure and blood pressure regulation, were carried out with 16 medical students in a problem-based learning curriculum. A qualitative, phenomenographic approach was used, and interviews were audiotaped, transcribed, qualitatively analyzed, and categorized. Four categories were outlined. The underlying principles were conceived as follows: 1) general conditions for body function at a specified time point, 2) transferable phenomena between organ systems and time points, 3) conditionally transferable phenomena between organ systems and time points, and 4) cognitive constructions of limited value in medical physiology. The results offer insights into students’ thinking about underlying principles in physiology and suggest how understanding can be challenged to stimulate deep-level processing of underlying principles rather than situational descriptions of physiology. A complex conception of underlying principles includes an ability to problemize phenomena beyond long causal reasoning chains, which is often rewarded in traditional examinations and tests. Keywords for problemized processing are as follows: comparisons, differences, similarities, conditions, context, relevance, multiple sampling, connections, and dependencies.

That misconceptions of underlying principles are frequent in medical physiology is hardly surprising in the light of the research on the outcome of learning in higher education in other areas. Such studies have shown that deeper understanding of principles that are central for the profession or study program (e.g., in engineering and economics) can be relatively poor. University studies often affect the students’ acquisition of subject-specific terminology and mastery of problem-solving algorithms but rarely the understanding of central phenomena (6).

Several studies have been carried out to explore the understanding of physiological phenomena among medical students. Misconceptions of respiratory (28) as well as perceived physiological responses (27) are common, and underlying conceptual difficulties, together with an inability to apply simple underlying principles in cardiovascular physiology, have also been shown (29). Felchtov and Spiro (11) have described cognitive features of misconceptions in biomedicine in general and cardiovascular physiology in particular among medical students. Oversimplification and reduction of inherent complexity are factors pointed to as being involved in the creation of misconceptions in physiology. Patel et al. (34) showed that causal rules, based on basic science information, are often applied inconsistently by the students. Their studies also showed a preponderance of superficial identification of concepts in novices, whereas more experienced students can use general laws.

Modell, from the Physiology Educational Research Consortium (PERC), argues that textbooks and teaching in physiology are often based on situational specific models that cause students to fail to recognize an underlying principle (30). PERC researchers have suggested an active learning environment (31, 32) and that “general models” (underlying principles) should be emphasized in the teaching of physiology (30).

Concept mapping (25, 26, 36), where students reflect over and connect concepts, and the use of analogies (14–16) have also attracted attention as valuable tools for supporting and evaluating understanding in medicine and physiology. Gentner et al. (13, 14) have, for many years, studied the use of similarities, analogies, and general laws in teaching. They argue that well-developed knowledge within a specific domain makes it easier to abstract and use general laws (15) and that transfer from one case to another can be promoted by an active negotiation exercise. Spiro et al. (37) warns about introducing oversimplifications by using intuitive analogies that can reduce the complexity of a phenomenon. The use of multiple analogies is recommended to avoid the misconception trap. The impact of PBL (2, 5) on students’ understanding of basic sciences has been debated (1, 16, 35). Hmel et al. (17) have shown that PBL students to a greater extent use hypothesis-
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situational descriptions of physiology. The students articulated the relationships between general principles of biomedical science and a specific case in clinical reasoning. Another study (33), however, showed that PBL students have a greater tendency to make errors when it comes to scientific facts and to generate less coherent explanations. The present study does not aim to compare PBL with other curricula. However, PBL is a part of the study context that needs to be considered in the interpretation of the results.

The teaching agenda suggested by Modell (30), of using general models in the teaching of physiology, builds on the perception that there is something such as a general underlying principle that can be transferred between different situations. He uses the term “general model” to describe underlying principles that can be transferred and applied in many different situations. Modell gives conservation of mass, mass and heat flow, transport across membranes, and elastic properties of tissue as examples of general models (underlying principles) that can be transferred between different situations in human physiology. Transfer of knowledge between situations, however, is complex and has been discussed in medical education literature previously (10).

Marton and Booth (20) make a distinction between “situation” and “phenomenon” that can be helpful in the discussion about general models and underlying principles in physiology:

A situation is always experienced with a socio-spatio-temporal location—a context, a time, and a place—whereas a phenomenon is experienced as abstracted from or transcending such anchorage.

However, they also argue that the two (situation and phenomenon) are intertwined and experienced together in the actual learning situation.

The definition of “underlying principle” in this study can be understood as an example (in physiology) of what Marton and Booth describe as a phenomenon. An underlying principle is experienced in a situation in human physiology (spatiotemporal location) but can also be identified in (or transferred and applied to) other situations in the human body and therefore transcend several situational descriptions. Our understanding is that this definition of underlying principle is commensurable with the term general model, which has been used by PERC researchers.

Another term, “concept,” is often used in educational literature and studies that address understanding in physiology, but the term is, however, seldom defined. The term “concept” does not, as we understand it, necessarily include the transferable characteristic of a principle. We feel that the terms “underlying principle” and “phenomenon” more clearly reflect the transferable characteristic that is focused on in this study.

This study explored how students discern and transfer underlying principles in medical physiology.

The aim was to provide a knowledge base for teaching interventions that can support deep-level processing and understanding of underlying principles (phenomena) rather than situational descriptions of physiology.

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Phenomenography: a Framework for the Study Design

The concepts of deep and surface approaches to learning (24) emanate from the tradition of phenomenographic research (19, 21) of learning. The first phenomenographic studies were qualitative and described how students approached reading texts (22, 23). The different approaches (deep and surface) were related to the outcome of the students’ understanding of the content. The student’s intention with the learning task appeared to be a crucial factor for the quality of the outcome of learning. During the same period, other researchers described similar findings in terms of various dimensions of the students’ learning process (3) and orientations to studies (9). A wide variety of inventories and questionnaires, based on the findings of qualitative researchers, have been developed over the years (8). The inventories are used to quantify the occurrence of various learning approaches in different learning contexts.

Phenomenographic studies address various conceptions of, or various ways of experiencing, a phenomenon. The researcher’s primary interest is not to uncover the true nature of something (e.g., blood pressure regulation) but to explore various ways it can be conceived of in a population (e.g., medical students). This feature of phenomenography is called the “second-order perspective.” The second-order perspective makes the approach suitable for studies addressing students’ understanding and their ways of conceiving of learning and learning contexts. Phenomenographic studies are generally based on interviews. The interview format offers an opportunity to get the informant to discuss a topic in depth. The interviewer uses probing strategies such as repeating, requesting clarification, requesting elaboration, and requesting confirmation. Interviews are transcribed and analyzed in terms of differences and similarities in content and structure. The analytical process is iterative and comparative. Transcripts are reread and analyzed from several perspectives (7). Results are presented in a category system. The categories describe qualitatively different conceptions that are present in the interview material. Categories are inclusive, which means that a conception in a higher category includes elements of the conceptions in lower categories. In other words, more complex conceptions are found in the higher categories.

In the more recent development of phenomenography, Marton and Booth (20) have suggested a model for the experience of learning as constituted by a WHAT aspect and a HOW aspect. The HOW aspect describes how students go about learning and their intentions with the learning task (e.g., approaches to learning). The WHAT aspect describes how the students perceive of the actual content they are learning (in this case, medical physiology). Marton and Booth’s model of the experience of learning was used as a starting point for the design of our study. In an earlier article, we (12) described four different approaches for achieving understanding of physiological phenomena. The present study explores how the same students conceived of underlying principles related to blood pressure and blood pressure regulation, i.e., their understanding of the content (the WHAT aspect).

This study was approved by the Ethics Committee for Human Research, Faculty of Health Sciences, Linköping University, Linköping, Sweden.

Context of the Study

The study was carried out in the medical program at the Faculty of Health Sciences of Linköping University. The program has applied PBL (2) since 1986 and is based on high levels of students’ own responsibility for learning. Students meet in tutorial groups (7–8 students) twice a week, and the maximum amount of scheduled time is 15 h/wk. Educational activities complementing self-studies and tutorials are lectures, laboratory work, skills training, interactive sessions with experts, patient communication training, and elective faculty resource sessions. Subjects are studied in an integrated manner and subdivided into themes, which are mainly organ based. The goals for the complete semester are assessed at the end of the study term. Tutorial work focuses on reality-based scenarios, mainly patient cases. The study was performed during the students’ fourth semester.
of studies, when all students had completed the first phase of the curriculum addressing normal body function.

**Interview Procedure and Analysis of Data**

Sixteen students were interviewed (7 women and 9 men; 15 students were 21–25 yr of age and 1 student was 30 yr of age). Interviews lasted ~1 h, and a semistructured interview guide, including the following four domains, was used: 1) what is physiology in general, 2) elaboration and discussion of physiological phenomena, 3) what does it mean to understand physiology, and 4) what strategies are used to achieve understanding. The results presented in this article focus on the second interview domain.

Students were asked to elaborate on the concepts of blood pressure and blood pressure regulation and then to identify underlying principles based on the physiology s/he had described. The question was rephrased several times to avoid semantic misunderstanding. Underlying and general principles, mechanisms, or simply similarities that could be seen in other organ systems or functions in the body were asked for. The discerned principles were applied to other organ systems (transferred to other situations in medical physiology) and elaborated on by the student. The question was repeated until no more objects of transfer could be discerned. All interviews were audiotaped and transcribed.

The analysis process followed the procedure of phenomenography (7) and included reading each transcript in its complete form. After detailed familiarization with each interview, *domain 2* was focused on. Qualitative characteristics were noted, and narratives were grouped according to differences and similarities in content and structure. Factors such as how the students discerned the principle, the structure of their reasoning when they elaborated on the principle, and how different principles were related and processed were analyzed. A first set of categories was suggested and then discussed and scrutinized in a series of meetings with senior researchers. Transcripts were reread, regrouped, and labeled until a stable set of qualitatively different categories had been established.

**RESULTS**

**Conceptions of Underlying Principles in Physiology**

The results comprises a set of four different categories that outline how the students conceived of underlying principles in physiology. Each category has a descriptive title and a label. Aspects of the category are exemplified by student quotes.

Underlying principles in human physiology are conceived of as follows: 1) general conditions for body function at a specified point in time (situatuated and undifferentiated); 2) transferable phenomena between organ systems and points in time (transferable phenomena); 3) conditionally transferable phenomena between organ systems and points in time (conditionally transferable phenomena); and 4) cognitive constructions of limited value in medical physiology (situatuated and differentiated).

General conditions for body function at a specified point in time (situatuated and undifferentiated). In this category, students discerned factors, such as oxygen level and nutrition status, that affect all organs, systems, or cells in the body at the same time. A phenomenon that transcends time and location was typically not discerned and transferred to a specific location or mechanism in the body. Rather, the description was situated, and factors affecting the whole body at the same time were described.

**STUDENT 13 ON THE OXYGEN LEVEL.** “…the oxygen level...there is oxygen in all cells, and it has an effect on all organs also if one, if some kind of hypoxia or ischemia or something occurs, then it will affect the function and the cells in the function of the organ, irrespective of which organ it is.”

**STUDENT 3 ON THE FUNCTION OF HORMONES.** “So the hormones, which affect the vessels, will also go down to the kidneys and affect them and maybe increase the blood volume. So it’s connected, yes. It’s often the same hormone. That is, the hormones affect the whole system.”

Transferable phenomena between organ systems and points in time (transferable phenomena). In the second category, students identified principles that are related to blood pressure and blood pressure regulation. Principles were correctly applied at several locations in the body. Phenomena such as feedback, flow-pressure relations, neuronal regulation, and diffusion were identified and transferred to new situations (other organ systems and other points in time). A dominating theme is the descriptions of different principles related to regulation and the overall aim of sustaining the balance in the body.

**STUDENT 14 ON NEGATIVE FEEDBACK.** Identified in blood pressure regulation:

- If the blood volume is increased as a response to aldosterone, an increase caused by angiotensin 2, then a normal kidney will be well perfused again and the secretion of renin in the kidney is decreased. So there you have negative feedback.

Applied in regulation of hormones:

- If you produce too much of a hormone, then you often have negative feedback on a higher level, the hypophysis, or even hypothalamus.

**STUDENT 4 ON RECEPTOR FUNCTION.** Identified in blood pressure regulation:

- …these receptors that are also in, they are in glomus caroticus, I think, and somewhere in aorta.

Applied in regulation of respiration:

- I think of respiration and the respiratory system…if you, for example, have high carbon dioxide, there are these kinds of receptors that sense it and makes us breathe faster…

Conditionally transferable phenomena between organ systems and points in time (conditionally transferable phenomena). As in the previous category, the students identified principles related to blood pressure and blood pressure regulation and transferred those to several locations in the body. However, new aspects were elucidated, which then resulted in a more complex conception. The underlying principles that were identified are seen as conditional, which complicates the picture. Different conditions, dependences, and relations between various principles were described. Principles were not seen as separate but as interacting with one another in complex patterns. Students were also aware that they were describing principles on different levels, from the human being as a system to a cellular or molecular level.

**STUDENT 5 REFLECTS ON CONDITION.** After identifying the principle of how flow, pressure, and resistance are related in the case of the blood pressure and applying it to the airways, student 5 reflected on differences, or various conditions, between the two systems:

- So that is an analogy, the pressure difference that was present in the circulatory system is also present in the lung, to be able to get in air. And there, the pressure difference is...
generated by the muscles quite simply, you inhale, increase the volume and a negative pressure occurs there, so if flows, the air flows into the lung, then you do the opposite, when you push, it quite simply becomes a positive flow, or pressure. It's more like a, I mean it shifts, in the circulatory system it's not supposed to shift, it should flow in one and the same direction all the time... but it's the same principle.

STUDENT 11 REFLECTS ON THE COMPLEX INTERACTIONS BETWEEN PRINCIPLES. “There are very many systems... that directly counteract each other... but I think there are more that do not directly counteract, but have sort of a “diagonal” effect on other... Take, for example, aldosterone, which does not really have its most important effect on the blood pressure but it gets... The most important thing about aldosterone is the balance of sodium and potassium, specially the concentration of sodium, but it has indirectly, through osmolarity, an effect on the blood pressure.”

STUDENT 15 REFLECTS ON LEVELS. After discussing principles such as homeostasis, feedback, and reflexes, student 15 reflected on level:

And then when you go on to cells, most cells work in the same way, even though some of them have special functions. Also how they look, but that’s histology I guess... that they make their proteins, for example, all of them do it according to the same principle, but in some, they may make proteins for secretion, others make proteins for themselves. I’m getting close to molecular biology here.

Cognitive constructions of limited value in medical physiology (situated and differentiated). This student (S7) said that underlying principles can be identified but that they are of very limited use in medical physiology. The hypercomplex system of interactions and conditions in the human body means that the construct of principles that transcends the situation is of very little interest. Like the first category, the fourth category is situated. However, the student was aware of the idea of transferable phenomena and how it could be used in medical physiology as a vehicle of information in human communication, but did not appreciate them as otherwise relevant in the hypercomplex system of interactions and variable conditions of human physiology.

STUDENT 7 ON MEDICAL TERMINOLOGY. “Both blood pressure, the endothelium, the heart and this, and the adrenalin and the different groups of cells that respond to change... so many of the words we use, for example, compensations or interaction or homeostasis, they are useful in a way, they still have some sort of function for carrying information, but they can be deconstructed and you can see how meaningless they are.”

Spread of Categories

The category system is hierarchic. Informants in categories 3 and 4 can also express elements of categories 1 and 2. But informants in, e.g., category 2, do not express elements of e.g., category 3 (Table 1).

DISCUSSION

Students’ understanding of specific underlying principles in physiology has been investigated and debated (27–30). The present study explored how medical students conceive of underlying principles in human physiology in general, not a specific phenomenon. The phenomenographic methodology (7, 19, 21) enables a student perspective. The findings point to different qualities in the way students discern and describe underlying principles. In the first category, factors or aspects that affect the whole body at the same time are discerned by students. Principles cannot be identified and separated from location and time. Phenomena, in the way they are described by Marton and Booth (20), that can be separated from time and space and transcend the situation cannot be identified in the first category. In the second category, phenomena that transcend different situations can be identified and adequately transferred between organ systems and situations in the human body. In the third category, students also discern phenomena that transcend the situation but express an awareness of the complexity of interactions and conditions in human physiology that affect the applicability of the principles in different situations. The way of reasoning about physiological phenomena is qualitatively different in the sense that phenomena are not simply mentioned or explained in terms of causal relations but processed and contextualized in various ways. There is only one student in the material who expresses the fourth conception. This student conceives of underlying principles as constructs that have a very limited value in medical physiology. The complexity of interactions, relations, and conditions of these principles are considered to be so strong that they have lost their meaning, apart from being vehicles of information in human communication. Again, as in the first category, medical physiology is situated. The difference between the first and fourth categories is, however, evident. The student expressing the fourth conception is aware of the construct of underlying transferable principles. There is an awareness of the complexity of the system that has led to a standpoint that medical physiology is situated. The fourth category is therefore referred to as situated and differentiated rather than situated and undifferentiated.

Understanding as Causal Reasoning Versus Understanding as Problemized Processing

Causal reasoning is often rewarded in physiology examinations. However, also very long and complex causal relations can be rote memorized. This study provides insights into how physiological phenomena can be processed beyond causal reasoning. Causal reasoning was common in students’ ways of explaining phenomena. However, students in categories 3 and 4 processed the causal chains in a way that was not seen in the other categories. We called this processing “problemized processing.” Problemized processing was characterized by 1) comparisons and identification of differences and similarities between situations where the phenomenon was present, 2) awareness of conditions for the phenomenon in various contexts, 3) awareness of relevance of the phenomenon in various contexts and in therapy and/or disease, 4) an ability...
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to identify the phenomenon in a number of situations in human physiology (multiple sampling), and 5) identification of connections and dependencies between different phenomena in the human body.

The difference between the second and third categories can be related to Biggs and Collis’ SOLO taxonomy (4). The causal explanations, seen in the first two categories, have a “relational” structure, whereas the third and fourth categories show elements of what Biggs and Collis describe as an “extended abstract” way of expressing the learning outcome. The students bring in new knowledge related to the phenomenon and discuss several outcomes of a situation. Patel et al. (33, 34) explored the clinical reasoning of medical students from a cognitive perspective. They described relations between different operations students perform as conditional or causal. Our data suggest that conditional reasoning is an important factor in achieving a more complex understanding of human physiology. However, the research approaches are different and comparing the results on a more detailed level is thus difficult.

Areas of Application

This study aimed to serve as a knowledge base for teaching interventions that can support deep-level processing and understanding of underlying principles in physiology. The study was carried out in a PBL curriculum. An awareness of qualitative differences in the students’ processing of physiological phenomena can be a helpful tool for the PBL tutor. By encouraging identification and transfer of underlying principles, comparisons between various physiological situations, and promoting reflections on the relevance and applicability of various principles, the tutor can support the group in problemizing underlying principles and help to prevent group work from getting stuck in memorized causal chains. This study was performed in a PBL medical curriculum. However, similar qualitative differences are likely to appear in other student groups, and tutor strategies may also be applicable in other types of active learning environments, e.g., in the laboratory or seminar form, where students are allowed to express and discuss their preconceptions and misconceptions of physiological principles. The ways in which students’ conceptions of physiological phenomena can be affected and changed by teaching interventions are, however, not within the scope of the present study and need to be addressed in various learning contexts in the future.

Connection to Learning Approaches: Suggestions for Future Studies

In an earlier article, we (12) described approaches the same students used to acquire understanding of physiological phenomena. Actively striving for a change in perspectives of the phenomenon and the use of multiple learning modalities were central features for the most complex category (the Moving Approach). These students actively exposed themselves to challenge and variation to acquire new perspectives of the phenomenon they were trying to understand, and the processes of developing understanding were considered to be an open-ended process. Understanding was continuously nuanced and refined by new information. The Moving Approach can be contrasted with the Holding Approach, where the students strive to reach a final goal. His/her understanding could be threatened by new input and challenges and was therefore “sealed” and “held on to.”

Students in the present study who express the third and fourth categories (conditionally transferable phenomena and situated and differentiated) displayed strong elements of the Moving Approach when they described their learning process, as presented in the previous article (12). The relations between learning outcomes and learning approaches are known to be complex (3). Our study is qualitative and the data are too limited for statistical analysis, but an interesting connection between learning approaches and learning outcome is indicated. A future project could be to develop inventories to quantitatively relate Holding and Moving Approaches to the qualitative differences in learning outcomes reported in this study.

Methodological Considerations

The interview situation in itself affects what the students express. We do not rule out the possibility that there are students who can express other conceptions in other situations. The categories are not considered to be static individual characteristics. The interview situation has, however, many similarities with the situation where the results are intended to be applied in a teaching and learning situation. One difficulty in a study addressing understanding is to get the students to express what they know in a new and challenging way and to go beyond rote memorized knowledge from textbooks. Several students said that the interview was a challenge as well as being helpful to them from a learning perspective. We feel that the study setup was successful. The concept of a challenging task and indepth interviews that required the students to clearly express their ways of thinking is interesting from a PBL tutor perspective.

The results do not show the amount of factual knowledge the student presented, a factor that also affects the quality of the learning outcome. Our observation is that students in the third category (conditionally transferable phenomena) also displayed a large amount of factual knowledge. Contextualizing, comparing, and discussing conditions require knowledge and facts. However, it cannot be ruled out that it might be possible to express this category and use fabricated knowledge.

Concluding Remarks

The study setup (with a challenging task, indepth interviews, and a focus on the students’ discernment and processing of underlying principles in physiology at several locations in the body) reveals new insights into students’ thinking about physiological principles. The phenomenographic second-order perspective places a student perspective on an area that has been long debated among teachers, namely, how underlying principles are conceived of by students. The findings point to different qualities in the way that students discern and process underlying principles that can likely be used to challenge and promote deep-level understanding in medical physiology. A complex conception of underlying principles includes an ability to problemize phenomena beyond long causal reasoning chains, which is often rewarded in traditional examinations and tests. Keywords for problemized processing are as follows: comparisons, differences, similarities, conditions, context, relevance, multiple sampling, connections, and dependencies.

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