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What Makes Physical Chemistry Difficult?

Perceptions of Turkish Chemistry Undergraduates and Lecturers

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Physical chemistry courses are traditionally considered difficult from both students' and lecturers' point of view *(1)*. Students come to physical chemistry courses with negative perceptions and low expectations. Lecturers' expectations and perceptions (what qualities students should have to achieve in their courses and what types of topics should be covered) usually vary markedly from students'. Most teachers and most students see physical chemistry as an immense body of accumulated knowledge, rather than viewing it as avenues that can be taken as we try to make sense of a part of the physical world *(2)*.

Factors influencing students' success in chemistry have been the subject of several research studies *(1–3)*. A vast majority of these studies have focused on students' understandings of specific concepts in chemistry. Less attention has been paid by the researchers to students' views of chemistry courses. A literature search reveals very few studies of this kind. In an earlier study, Carter and Brickhouse *(3)* undertook research to find out students' views of learning difficulties in chemistry. The study started with two open-ended questions following the development of a questionnaire that was given to 1200 first-year chemistry students and 14 faculty members. Factors influencing students' views were grouped under three headings; student-controlled factors, course-related factors, and factors inherent in the nature of chemistry. Their study explored several common and discrepant views between students and lecturers, and paid attention to the effects of these views on the quality of students' learning in chemistry. A few years after this study, Australian researchers Kirkwood and Symington *(4)* designed a qualitative study into perceptions of individual staff members of the difficulties facing students in a first-year chemistry program. All nine staff in the department were interviewed and the data were then analyzed qualitatively. The staff members' views were grouped under two headings: "perceptions of students' difficulties" and "perceptions of solutions to students' difficulties". The results indicate that there is a lack of awareness among lecturers concerning a great deal of research findings reported in the past decades about students' learning in science.

Nicoll and Francisco *(1)* have recently researched students' learning difficulties in physical chemistry, analyzing data from a total of 77 chemistry and chemical engineering majors enrolled in physical chemistry courses at two different universities and taught by the same professor. The data gathered at the beginning of the course about students' perceptions of the course and their abilities were compared with the students' actual performance in the course at the end of the term. A nationwide survey was carried out with 28 professors of physical chemistry in order to determine their views of students' learning difficulties in physical chemistry. The results of the study suggest that lecturers' and students' views of students' learning difficulties in physical chemistry are quite different from each other, with neither group's responses matching reality. The study also indicates that there are different factors affecting students' success in physical chemistry beyond students' mathematics skills and logical thinking skills *(1)*.

On the other hand, some studies report promising new teaching approaches using information technology to help students better understand physical chemistry *(5–9)*. These studies describe changing pedagogical strategies that move toward more teamwork with constructive interdependence among students and faculty; these pedagogical strategies also emphasize the importance of context-rich teaching materials. For example, one study described a teaching approach that covered chemical kinetics and emphasized the importance of moving from analytical solutions of rate laws to simulation of complex chemical reaction system as used in industry *(7)*.

Research in this area is focused on determining what factors influence students' performance in general chemistry courses *(3–4)* and students' understanding of specific concepts in areas of chemistry *(10–14);* relatively little research has been done on student perceptions of physical chemistry *(1)*. The content of a course can be perceived differently by students and lecturers because of differences in their experiences, knowledge, understanding, goals, and interests. We may better understand students' learning difficulties in physical chemistry if we understand student and lecturer perceptions of the course. Student perceptions of a course influence their motivation and interest in the course and as a result may influence their learning. Lecturer perceptions of a course, however, influence design of the course, choice of curriculum, implementation of curriculum, and the nature of evaluation in the course *(3)*. Thus, both student and lecturer perceptions of physical chemistry courses are central to creating a successful teaching and learning environment in the classroom. The study presented in this paper, undertaken as part of a longitudinal research project *(15),* examines student and lecturer perceptions of students' learning difficulties as well as possible solutions proposed by them in physical chemistry. This study also compares students' learning difficulties in Turkey with those of students studied elsewhere.

Methodology

Data Collection

The data for this study were collected from two different chemistry education departments in two universities in Turkey.

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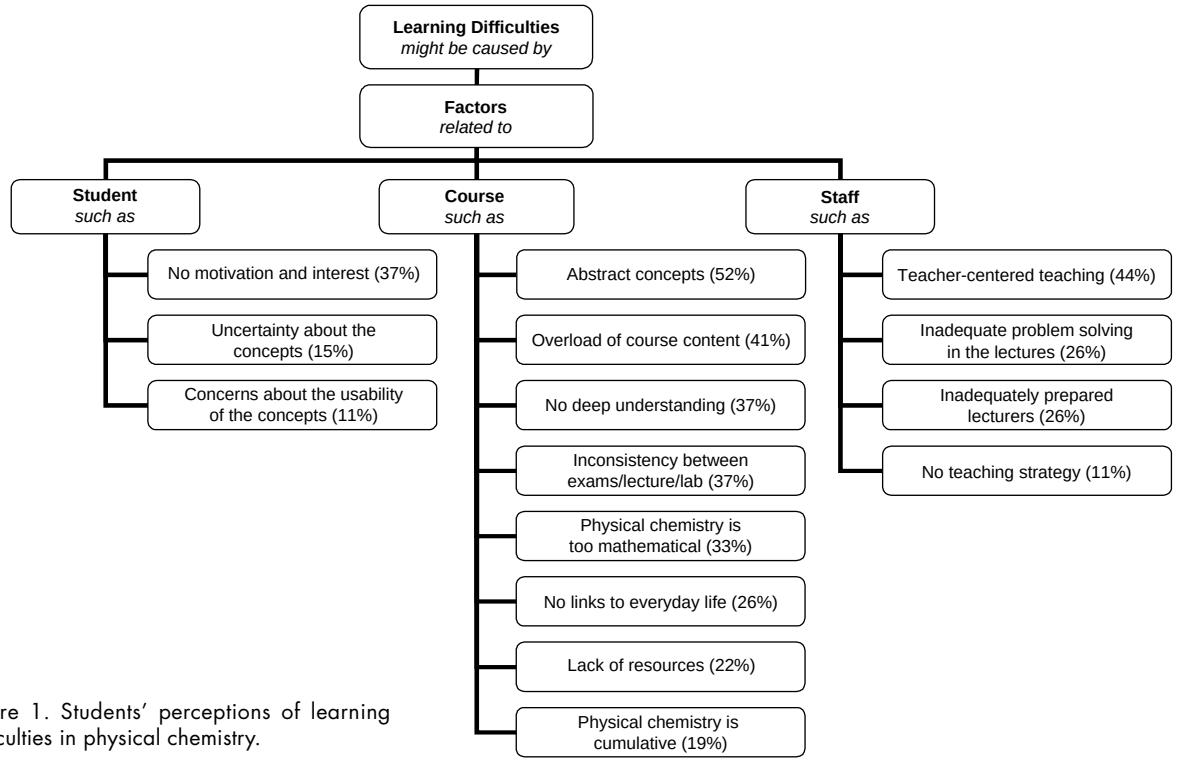

Figure 1. Students' perceptions of learning difficulties in physical chemistry.

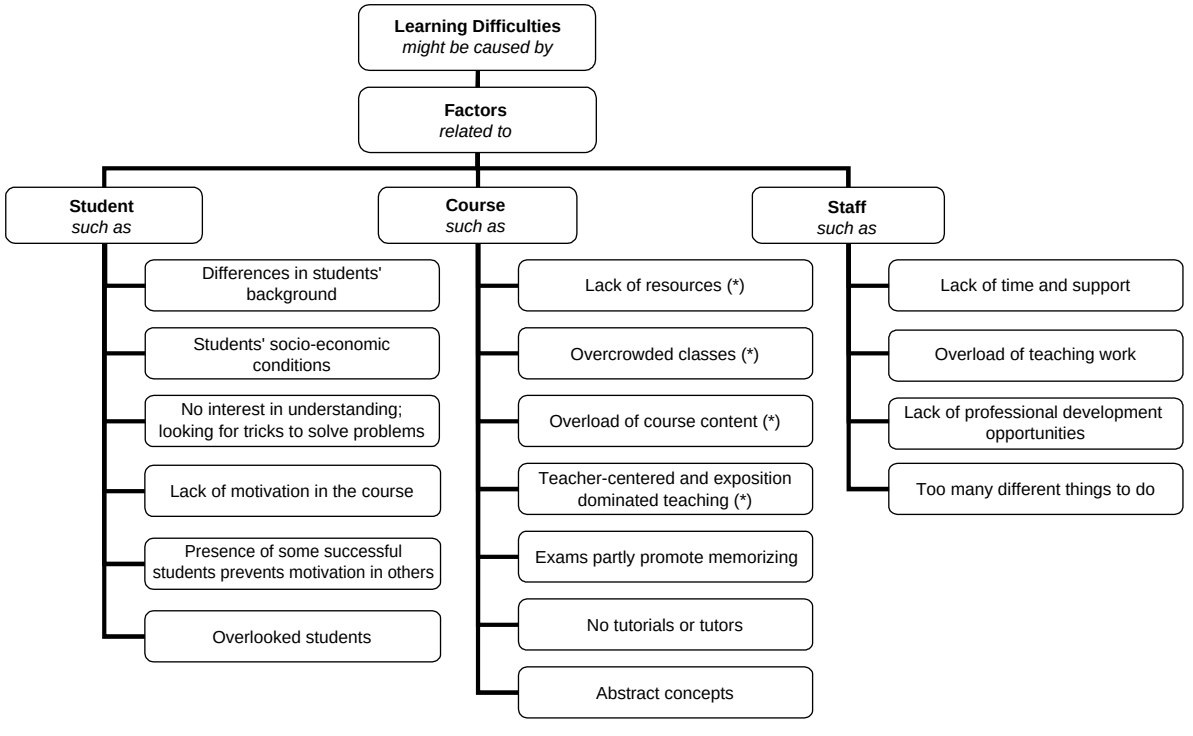

Figure 2. Lecturers' perceptions of students' learning difficulties in physical chemistry. Percentages were not calculated since only two lecturers were interviewed; an asterisk indicates views shared by both of the lecturers.

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One of the universities is in western Turkey and the other is in eastern Turkey. Both universities are classified in the top twenty of the Turkish Universities League. The students (third-year undergraduates) involved in the study were enrolled in a Physical Chemistry II course (4 hours per week and 14 weeks in a semester) in the students' sixth semester. One of the departments conducted four hours of laboratory work per week in parallel, while in the other department the laboratory course was given the following year. There were 47 majors in one of the departments and 44 in the other. The content and the design of the courses were similar in both departments as determined by the lecturers.

A researcher collected the data during a 50-minute lecture period that took place at the end of the sixth semester after students were taught physical chemistry. Students were asked to work in pairs or groups of three and were provided with a free-response survey sheet containing two questions:

1. What do you think makes it hard for you to understand chemical ideas in physical chemistry? Please discuss this with your friends in a group and write down your thoughts.
2. What do you think could be done to help you understand these ideas better? Please discuss this with your friends in a group and write down your thoughts.

In addition to the student survey, two lecturers who had taught the physical chemistry courses in the participating departments were interviewed. The interviews were unstructured and they started with this introductory question: *What do you think makes it hard for the students to understand chemical ideas in physical chemistry?*

A discussion of issues raised by the interviewees followed. The interviews were carried out in lecturers' offices and lasted about an hour. One of the lecturers agreed to be tape recorded and the other one did not; notes were taken during the interview.

Data Analysis

Findings from the interviews are charted in four diagrammatic representations: two show the perceived students' learning difficulties (Figures 1 and 2) and the other two relate the proposed ideas to overcome these difficulties (Figures 3 and 4). Percentages were not calculated because only two lecturers were interviewed, however the views shared by both of the lecturers were indicated with an asterisk (*). Analysis of the results was based on a qualitative analysis of students' written responses. Initially, all the responses were read, patterns were identified, and the first categorization was done. Responses were tallied and finally similar categories were combined and the final categorization was made and percentages calculated. The students' perceptions were then conveyed in diagrammatic representations, including the percentages (Figure 1). Perceptions of learning difficulties and proposed solutions were categorized as *course-related*, *student-related,* and *staff-related* difficulties (Figures 1 and 2) or solutions (Figures 3 and 4).

Results and Discussions

Similar Perceptions

Student and lecturer perceptions of students' learning difficulties in physical chemistry are summarized in Figures 1 and 2, respectively; the proposed solutions are given in Figures 3 and 4. The figures indicate that the lecturers and students were in agreement in some cases. The abstract nature of concepts in physical chemistry, the overload of course content, insufficient resources, teacher-centered and exposition-dominated teaching, and the lack of student motivation are the major issues that were thought to affect students' learning in physical chemistry both by students and lecturers.

Figure 1 shows that more than half of the students (52%) perceived the chemical concepts in physical chemistry to be abstract and 26% of the students argued that the physical chemistry course does not make links between the concepts being taught and everyday life. They found it hard to visualize the abstract concepts, and to make them understandable and applicable to the macrophysical world. Lecturers' views are in agreement with students' view, as seen from Figure 2. As a way of overcoming this difficulty, a significant number of students (56%) proposed that if links could be made between the concepts in physical chemistry and their applications to industry and everyday life, it would be much easier to understand physical chemistry. These findings show similarities with the previous studies.

The abstract nature of chemical concepts in general is the issue that many consider as one of the main factors affecting students' success in chemistry, particularly in physical chemistry. There are numerous studies done on concept learning. In teaching abstract concepts, it is commonly argued that using pseudo-examples, designed to reveal the critical and variable attributes of a concept, would help learners *(16).* However, in using pseudo-examples, care has to be taken not to give an incorrect impression or information about concepts. For example, in the models used in chemistry teaching, atoms are distinguished from each other with different colors: oxygen is red, carbon is black. Care must be taken to vary these features across pseudo-examples so that the student can appreciate that they are not actual characteristics of the concept being taught.

The second issue that both students and lecturers agreed on was the number of courses and the contents of these courses. Forty-one percent of the student responses indicated that the course contents were overwhelming. Both lecturers also recognized that the course content is overloaded and there are too many courses. In their third year students usually take at least 7 different courses, with a total of 18 lecture hours a week. Anecdotal evidence and research *(3–4)* suggest that students are dissatisfied by overloaded course content. Students complain that there are too many new concepts to be learned in a short period of time. They also state that lecturers decide to cover a certain number of topics without considering whether topics are understood or not. In this case, teachers as professionals are in a position to decide whether the quality or quantity of concepts is important. The constructivist view of teaching emphasizes the importance of quality rather than quantity in science teaching *(12).* This view also requires a flexible curriculum that could be shaped according to the rate of students' learning and students' needs and demands. It appears that there is a need for a careful examination of undergraduate curricula and its implementation, as well as the lecturers' workload.

Approximately one in five (22%) of the students and both lecturers complained about the lack of resources and

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quality textbooks written in Turkish. They stated that the facilities, such as library, study rooms in the department, handouts, or written documents that can be used for self-study, are either not available or are inadequate. This issue appears to be mostly related to the economic development of the country rather than a general issue of learning difficulties. The education language is Turkish in the majority of the universities in Turkey and most of the students lack foreign language skills. There is a limited number of quality physical chemistry textbooks, self-study materials such as handouts, research reports, and journals written in Turkish, although the numbers are increasing in recent years. This leaves students in a disadvantaged position and also leads to students demanding better resources.

The fourth point that both students and lecturers seem to agree on was the fact that teaching was mostly driven by the lecturer using exposition-dominated methods. Forty-four percent of the students showed dissatisfaction with the teacher-centered teaching approach and 19% of the students proposed student-centered teaching as a solution to this problem. Further, 33% of the students also proposed that promoting the use of educational technology may help students to understand physical chemistry better.

The final point that both students and lecturers agreed on was the lack of students' motivation and interest in physical chemistry courses. This point was raised by 37% of the students and one of the lecturers. Lack of motivation in physical chemistry courses may be due to the poor image of the course, including the abstract nature of concepts and the high level of mathematical knowledge required. If students could become better motivated, many of the perceived problems and much of its perceived difficulty might be significantly decreased.

Discrepant Perceptions

Although there was a great deal of agreement between students and lecturers on the causes of learning difficulties in physical chemistry, there were some important discrepancies as well. In this case, 37% of the students argued that there is no promotion of conceptual understanding, and that they learn to pass the exams, not to understand. The accuracy, consistency, and the validity of the assessment have been found to be problematic from the students' point of view by other researchers *(3)*. However, in this study, the biggest student dissatisfaction was about the written exams that force students to memorize material instead of understanding concepts. Students argued that they had to simply memorize the definitions and facts about concepts or equations in order to pass the exams. In addition, some of the students also argued that there is no need to understand the idea behind the concepts, because the exams test how to manipulate data to solve problems. The idea that more problem solving might help to improve understanding was shared by 48% of the students. Moreover, despite the lecturers' view that students do not want conceptual understanding, 19% of the students stated that promoting conceptual understanding might improve their learning of physical chemistry. Further, one-third of the students proposed that if more attention was given to frequently confused concepts and if the concepts were introduced in a hierarchy from simple to complex the students' understanding of physical chemistry might be improved.

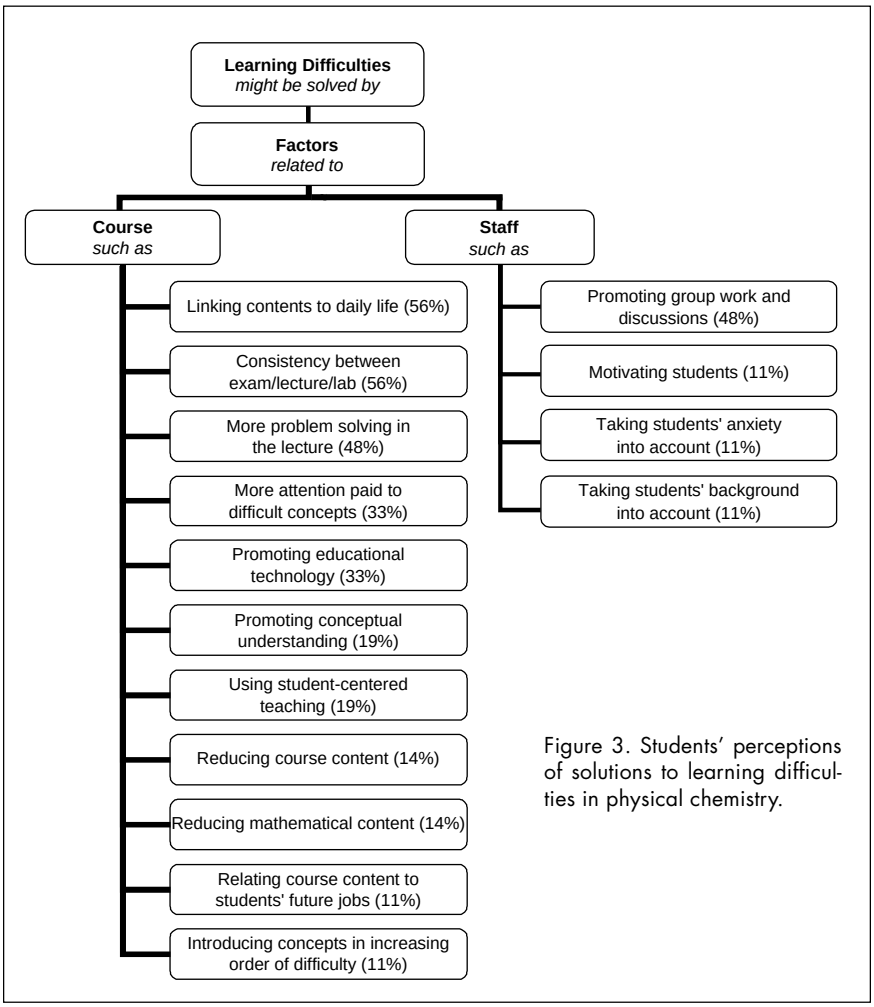

Figure 3. Students' perceptions of solutions to learning difficulties in physical chemistry.

The inconsistency between exams, lectures, and lab was perceived as a problem by 37% of the students and one of the lecturers. In one of the participating departments, the laboratory and the theoretical course were offered in the same semester, while the laboratory course was given in the following year in the other department. Most of the complaints were focused on the theoretical course content and the laboratory course content. There was an overwhelming demand by 56% of the students that a relationship between exams, lectures, and lab should be established. This was the second-most frequently proposed idea by the stu-

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dents to improve learning. It seemed that this demand is either missed or not perceived as an important factor by the lecturers. Anecdotal evidence supports the students' view. Lecturers explain why different topics are covered in laboratory courses by asserting that the wide content of physical chemistry is better spread out between the theoretical course and laboratory course. For example, one of the participating departments taught phase diagrams in the laboratory, not in the theoretical course. Students perceive this as a barrier to learning because they argue that doing experiments in a topic that they have not been taught makes it hard to understand the concept.

It has been always a subject of discussion among students that physical chemistry is dominated by mathematics *(1)*. One-third of the students argued that physical chemistry is too mathematical. The same may also be applied to chemistry in general *(1, 3)*. The results of this study show that one of the most common complaints about the lecturers was the use of high-level mathematics while giving less priority to the conceptual aspects of the chemical content. Despite the fact that 33% of the students complained about the mathematical content of the course, only 14% of them proposed that making the course less mathematical would help improve understanding. This result supports the previous studies suggestions *(1)* that mathematics alone is not the best predictor of students' performance in physical chemistry. Although students' mathematics skills play an important role in comprehending physical chemistry, the results suggest that this is a common prejudice, as only one in six students proposed reducing the mathematics in the course. Moreover, the number of mathematics courses that students take before entering physical chemistry has no correlation with actual performance in physical chemistry *(1)*.

Almost one in five of the students (19%) perceived physical chemistry as cumulative. It was argued that if a student missed a lecture it was very difficult to catch up as subsequent lectures rely heavily on previous ones. This finding indicates a similarity with the students' views of chemistry in a previous study *(3)*.

On the other hand, there were some issues that lecturers perceived as preventing better learning that were not recognized by students. The first one that both lecturers agreed on were overcrowded classes. They proposed that reducing the size of the classes might enhance teaching and learning, since different teaching methods could be applied, such as group work and discussions; smaller class sizes also help to provide a better laboratory environment for the students. One of the lecturers stated that the lack of tutors and tutorial hours discouraged better teaching. He proposed that more tutorial hours should be arranged, but to do this there must be adequate staff available.

Finally, students proposed suggestions to promote better conceptual understanding. One-third (33%) advocated the use of educational technology such as videos, slides, demonstration kits, computer programs, and so forth. There were some concern about the relationship between the course content and students' future jobs. Both the research and anecdotal evidence suggest that students have concerns about how they will benefit from such a high level of knowledge of physical chemistry in the future. This concern can affect students so that they do not view what they are learning as valuable. In contrast, learning theories tell us that students must see value

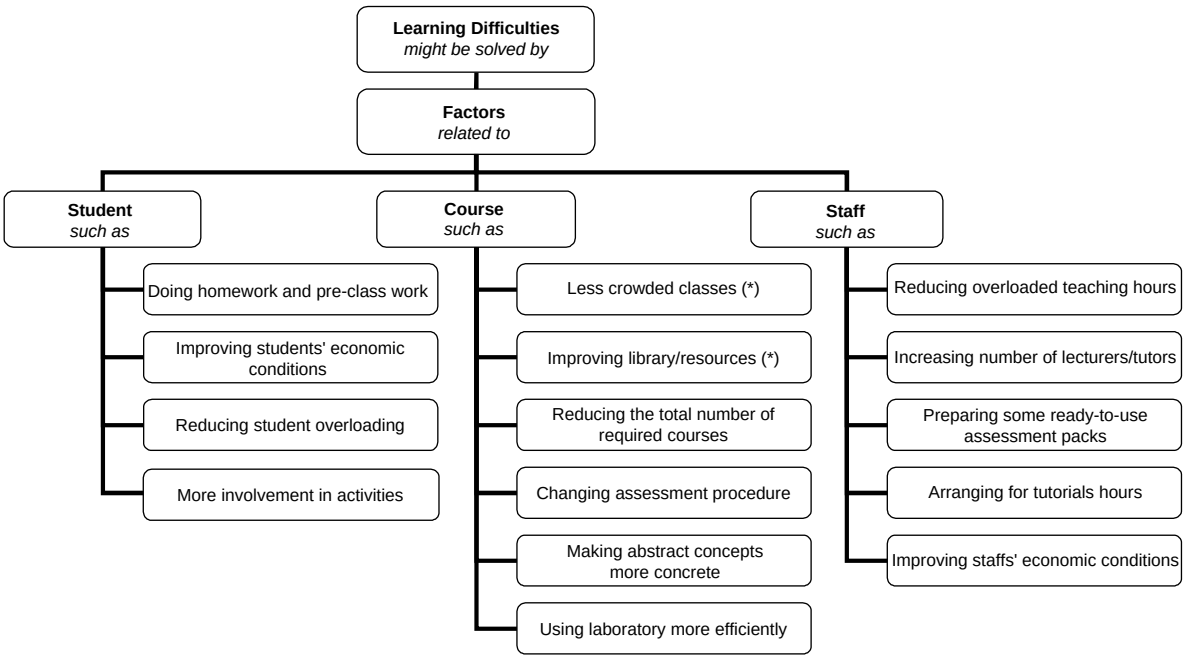

Figure 4. Lecturers' perceptions of solutions to students' learning difficulties in physical chemistry. Percentages were not calculated since only two lecturers were interviewed; an asterisk indicates views shared by both of the lecturers.

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in what we ask them to do and teachers must see the value in what students are allowed to do *(16)*.

Conclusions

This study investigated Turkish student and lecturer perceptions of students' learning difficulties in physical chemistry and reported possible solutions proposed by them to solve these difficulties. Identifying students' and lecturers' perceptions could help lecturers organize physical chemistry courses that better meet students' needs. Rightness or wrongness of the perceptions is not the issue of concern. The important issue is the parallel realities of the physical chemistry classroom, and how these influence what our students learn *(3)*.

Although it is not appropriate to generalize from a single study, the findings suggest that students and lecturers perceive the learning difficulties quite differently. Lecturers and students were partly in agreement on the learning difficulties related to the nature of the course, and the discrepancies were mostly related to student- and staff-related difficulties. Students were critical of the amount of course content, the resources available, and the teaching methods lecturers used. On the other hand, lecturers generally focused on systemic factors, such as overcrowded classes, lack of resources and staff, and students' academic background and socio-economic conditions. The findings suggest that there is a great deal of discrepancy between staff and student perceptions, although some points about the course-related difficulties were shared by both sides. These common themes and discrepancies may be used to improve the quality of teaching and learning in physical chemistry courses.

Among the students' difficulties, the abstract nature of thermodynamic concepts was a common theme that was also recognized by the lecturers. The other difficulty, which related to the nature of the thermodynamics or general physical chemistry, was the mathematical content of the course. The remainder of the difficulties relating to the course focused either on teaching methods or the physical conditions of the teaching environment. The lecturers generally emphasized the difficulties relating to the poor teaching environment as preventing better teaching. However, the interview data suggest that the lecturers have not given sufficient thought to how students learn. This might be due to a lack of pedagogical content knowledge. It seems from the students' concerns and proposed solutions that there is a demand for the pedagogical aspects of teaching and learning to be considered. It appears that there is also a need for a careful examination of the content of the undergraduate curricula and the ways in which curricula are implemented. Overload of course content creates problems both for lecturers and students.

The results of this study also indicate a parallel belief of the students' and lecturers' perceptions of learning difficulties in chemistry in general as identified in previous studies. When the results of this study are compared with previous studies *(3–4),* the similarities in views about students' learning difficulties seem to fall into the area of the nature of chemistry or physical chemistry. Differences between the groups arise from the different education systems of the countries. These results indicate that the content and teaching approaches of physical chemistry courses should be reconsidered, moving from textbook- and derivation-driven courses to providing informative, interesting, content-rich materials to help students learn. Some of the mathematical burden can be removed by the appropriate use of software to enable students to focus on learning the significance of physical chemistry *(17)*.

It is also important that chemical entities be defined qualitatively and their effects discussed before they are defined quantitatively. Problems could first be asked that are answerable in qualitative terms; only later, when there is a reasonable understanding of the meanings attached to the chemical entity, should derivations and numerical calculations be introduced. This suggests a reversal from the usual procedure where derivations and calculations are presented, students become proficient at manipulating the numbers to get the correct answer, with understanding following much later, if at all *(12)*.

Finally, learning is a complex process and the factors that influence what we learn are numerous. The variables that affect a person's learning have been categorized in four areas: characteristics of the learner, nature of learning activities, nature of assessment, and characteristics of materials *(16)*. It is the teachers' role, as instructional designers, to meaningfully coordinate these four variables influencing learning.

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