Published online: 3-16-2011

Characteristics of Problems for Problem-Based Learning: The Students' Perspective

Nachamma Sockalingam
Republic Polytechnic, nacha_sockalingam@hotmail.com

Henk G. Schmidt
Erasmus University Rotterdam, schmidt@fsw.eur.nl

Recommended Citation

Characteristics of Problems for Problem-Based Learning: The Students' Perspective

Nachamma Sockalingam and Henk G. Schmidt

Abstract

This study aimed to identify salient problem characteristics perceived by students in problem-based curricula. To this end, reflective essays from biomedical students (N = 34) on characteristics of good problems were text-analyzed. Students identified eleven characteristics, of which they found the extent to which the problem leads to desired learning outcomes as the most important characteristic. The extent to which the problem stimulates elaboration and the extent to which the problem promotes team effort were considered to be the least important problem characteristics. We clustered the eleven characteristics into two categories, "features" or "functions," based on the perceived roles of the characteristics. Identification and clustering of the eleven characteristics provide a useful basis for future problem design and evaluation.

Problems are considered to be one of the three key elements of problem-based learning (PBL); the other elements are students and tutors (Majoor, Schmidt, Snellen-Balendong, Moust, & Stalenhoef-Halling, 1990). Problems in PBL refer to the instructional materials presented to students to trigger their learning processes. Problems are often presented in text format, sometimes with pictures and computer simulations. They typically describe situations or phenomena set in real-life contexts, which require students to explain or resolve the presenting issues (Hmelo-Silver, 2004). The current study aimed to understand which characteristics of problems are perceived by students to be associated with good problems. While it is possible that students and problem designers may value different aspects of problems, understanding the students' perceptions will allow us to gain an insight into what motivates or helps the students to learn so that we can incorporate these characteristics in future problems to determine if students' perceptions of good problems are useful in designing problems.

In PBL, students follow the seven-step model to explain or resolve a problem (Schmidt, 1983). In this approach, students first discuss and analyze the problem in groups. This leads to the generation of several issues or topics that require exploration. Students then use these unresolved issues or topics as guidelines for their self-directed learning activities. During the period of self-directed learning, students find more information to answer or solve the problem. Following that, they reconvene, present to one another, and compile the information gathered. This results in integration of their new knowledge in the context of the problem (Hmelo-Silver, 2004).

As problems initiate students' learning processes, the quality of problems can be postulated to be crucial for students' learning. To investigate this and examine the relationships among the various elements of PBL, Gijselaers and Schmidt (1990) asked students in a PBL curriculum to rate 1) the quality of problems, 2) the tutors' performances, 3) their prior knowledge, 4) the extent of their group functioning, 5) time spent on individual study, and 6) their interests in the subject matter, using a rating scale. The authors then analyzed the influence of these key elements on students' academic achievements by means of causal modeling. In their causal model, they categorized the quality of problems, tutors' performances, and students' prior knowledge as "input" elements; group functioning and self-study time as "process" elements; and interests and academic achievements as "output" elements. The results showed that of the three input elements, the quality of problems had a more direct and stronger influence on the various process and outcome elements, and thereby supported the postulation that a good problem leads to improved learning.

A study by van Berkel and Schmidt (2000) reexamined the relationships among the earlier mentioned elements of PBL (Gijselaers & Schmidt, 1990) using the causal modeling approach as well. Results from this study confirmed and added support to the earlier findings on the importance of the quality of problems. Probing further, van den Hurk, Wolfhagen, Dolmans, and van der Vleuten (1999) investigated the influence of the quality of problems and tutorial group processes (e.g., breadth and depth of discussion in the tutorial group) on generation of useful learning issues. They found that the quality of the problems indeed had an influence on the generation of useful learning issues. This is in line with earlier work by Dolmans, Schmidt, and Gijselaers (1995), which demonstrated that the extent of correspondence between student-generated and faculty-intended learning issues could be used as a measure of the effectiveness of problems. Given the evidence for the importance of the quality of problems, Dolmans et al. (1995) contended that additional information about the nature of problems is required to improve the quality of problems. To this end, they suggested that determining the characteristics of problems is likely to provide insights on designing and assessing problems in PBL. A review of the existing PBL literature showed that while there are some studies that shed light on the characteristics of problems in PBL, these are relatively few when compared with studies on other aspects of PBL (Jonassen & Hung, 2008). We present in the next section an overview of the exist-

ing literature on problem characteristics, thereby identifying the gaps in our knowledge about characteristics of problems, which led to the questions asked in this study.

Overview of Literature on Problems in PBL

Generally, problems are designed based on guidelines derived from experiential knowledge and theoretical principles of learning and cognition (Dolmans, Snellen-Balendong, Wolfhagen, & van der Vleuten, 1997). For instance, Shaw's (1976) guidelines proposed five dimensions of problems, namely difficulty, solution multiplicity, intrinsic interest, cooperation requirements, and familiarity. Dolmans et al. (1997) outlined seven principles of problem design. These indicated that problems should 1) simulate real life, 2) lead to elaboration, 3) encourage integration of knowledge, 4) encourage self-directed learning, 5) fit in with students' prior knowledge, 6) interest the students, and 7) reflect the faculty's objectives.

Hung (2006) proposed a conceptual framework for problem design in the form a theoretical 3C3R model. The 3C3R model represents three core components and three process components of problems. The core components refer to content, context, and connection, which underpin the students' content and conceptual learning. On the other hand, the process components (researching, reasoning, and reflecting) represent the students' cognitive processes and problem-solving skills. Jonassen and Hung (2008) focused on one of the problem characteristics—problem difficulty—and defined it to be characterized by problem complexity and problem structuredness. According to these authors, problem complexity refers to the breadth, attainment level, intricacy, and interrelatedness of problem space while problem structuredness represents the intransparency, heterogenicity of interpretations, interdisciplinary, and dynamicity of problems. Although these guidelines and principles are useful to gain a better understanding about problem characteristics, these are theory based (Jacobs, Dolmans, Wolfhagen, & Scherpbier, 2003); there is still a lack of empirical studies to validate these theoretical ideas (Jonassen & Hung, 2008).

The few existing empirical studies on characteristics of problems in PBL tend to focus mostly on a few specific problem characteristics. For instance, Jacobs et al. (2003) developed and validated a questionnaire to assess the degree of complexity and structuredness of PBL problems. They defined complexity as the number of characteristics or variables that play a role in challenging the students to think and learn. Structuredness of a problem is characterized as requiring the application of a limited number of well-structured rules, with solutions that are straightforward and predictable. Therefore, a well-structured problem is thought to have one defined solution compared to an ill-structured problem, which may have many possible solutions. The authors found that although students could clearly differentiate between simple and well-structured problems, they were not able to discern ill-structured from complex problems. Hence the authors classified both ill-structuredness and complexity as factors of problem difficulty.

Using an experimental approach, Soppe, Schmidt, and Bruysten (2005) investigated the influence of problem familiarity on students' learning. They defined familiarity as the extent to which the students relate to the characters or actors represented in the problem. Their hypothesis was that the familiar version of the problem would activate more of the students' prior knowledge, which would, in turn, stimulate more of their interest, resulting in longer time spent on self-study and higher achievement scores on a knowledge test. To verify this, they presented two groups of students with either a familiar or an unfamiliar version of the same problem. The familiar version of the problem was set in a context involving students and their housing facility, while the unfamiliar version used the context of a consultancy firm. The intended learning issues for both problems remained the same and pertained to human judgment and decision making. To measure the influence of the problem context, the students were asked to rate the problem they had worked on based on its level of interest and familiarity. In addition, other indicators of learning, such as the number of explanations generated by students, the quality of the learning issues, amount of self-study time, and amount of knowledge acquired, were measured. The results showed that the students perceived the familiar version of the problem to be more interesting than the unfamiliar version. However, there was no significant difference in their academic achievement. One possible explanation given was that the difference between the familiar and unfamiliar situation was too subtle, hence resulting in negligible differences in the learning outcomes of the two types of problems. Another possible reason not mentioned by the authors is that although familiarity may be one of the meaningful characteristics for rating problems, it may not be the only characteristic. Overall, even though studies focusing on a few selected characteristics provided more information about the specific characteristics studied (Jacobs et al., 2003; Soppe et al., 2005), a drawback is that the findings are limited to few characteristics; they do not shed light on other problem characteristics.

To identify a more comprehensive list of essential problem characteristics, Des Marchais (1999) used a Delphi technique whereby he asked six PBL experts to identify three criteria considered most essential for the design of problems. This Delphi approach led to the identification of nine criteria that were ranked by the experts according to importance. The two most important criteria identified were that the problem should stimulate thinking or reasoning and lead to self-directed learning in the students. Although Des Marchais' (1999) study was the first to identify a comprehensive list of problem characteristics using an empirical approach, a point to note is that this study is based on expert's perceptions. It is possible that experts do not experience the problem in the same manner as students. Studies show that students' and tutors' perceptions of various aspects of students' learning may differ (e.g., Zanolli, Boshuizen, & De Grave, 2003). Given that students are the end users of the problems, it is reasonable to infer that identifying problem characteristics based on students' experiences is likely to provide a more valu-

able insight on what types of problems work well. This may raise the question of whether students' perceptions are reliable. Such concerns are partly addressed by studies that test the reliablility and validity of students' ratings on teaching skills and adequacy of instructional materials. The results from these studies showed that students' ratings can be reliable and valid, and therefore useful (Cohen, 1981). Another question that may be raised is whether students' perceptions of problems indeed reflects better learning. While this remains to be tested, it is worth noting that there is not enough research carried out to first explore the students' perspectives.

To include the students' perspectives, Schmidt (1985) developed a 59-item rating scale on various aspects of problems and administered it to 102 students. The data collected were factor analyzed. A total of eight independent characteristics of problems were identified using this approach. The identified attributes were learning output, goal clarity, openness, concreteness, familiarity, prior knowledge involved, time on task, and intrinsic interest. Although this study included the students' perspective, the items of the rating scale were derived based on a priori theoretical considerations. That is, the students were restricted to responding on the given characteristics. There is a possibility that students may consider characteristics other than those represented by the rating scale. Hence, we felt that a bottom-up approach to understanding students' perceptions was necessary.

In summary, some of the shortcomings of the existing literature on problem characteristics are that 1) they are generally theory-based and not evidence-based, 2) the relatively few empirical studies focus on only a few specific characteristics, and 3) studies that have attempted to explore the quality of problems at a broader level are restricted to expert's perceptions or a priori theoretical considerations. To address these shortcomings, the present study aimed to investigate students' perceptions of characteristics associated with good problems in PBL using an explorative approach. The specific research questions asked in this study were 1) which are the salient characteristics of PBL problems in students' perceptions? 2) which of these salient characteristics are perceived by students as being the most important? and 3) what can we learn from students on problems for PBL? To this end, we asked students to reflect and record their perceptions of what makes a good problem in their e-journal.

Method

Participants

This study was carried out during the second semester of academic year 2006-2007 at the School of Applied Science, Republic Polytechnic, Singapore. Participants were 34 second-year students taking a Microbiology module as part of their course to Diploma in Biomedical Sciences. A total of 239 students in 11 classes were enrolled in the Micro-

biology module. Participants were from 2 of the 11 classes; 18 students were from class 5C and 16 were from class 5Q. Both classes were facilitated by the first author. The mean age of participants was 18.41 (SD = .66). Of these, 41.2% were males and 58.8% were females. The participants' mean age and gender distribution was similar to that of the entire cohort of 239 second year Microbiology students (mean age = 18.5, 41.4% males, 58.6% females). We chose second-year students for the study as they would have been through at least three semesters (48 weeks) of studies and would be familiar with the PBL system and problems used in PBL.

Educational Context

PBL is implemented at Republic Polytechnic in a unique "one day-one problem" approach. Second-year students in the Polytechnic pursue specialized modules based on their chosen diploma course. At the time of study, each module comprised 16 problems. In the one day-one problem approach, students are required to complete one problem a day. Each day is divided into three meetings, with a self-study period between each meeting. The students are presented with the problem in the first meeting, during which students discuss the general outline of the problem with their teammates and facilitator. Students are then given an hour for self study to explore what they know, do not know, and need to know and to gather information. Following this, students and facilitator reconvene at the second meeting to discuss their progress. At the end of the second meeting, students are given a second self-study period for two hours to compile the information gathered and prepare for their team's presentation. During the third meeting, students present their findings to the class for discussion. Finally, the facilitator helps to summarize the various points discussed and relate it to the key learning objectives of the problem. A more detailed description of the PBL process at Republic Polytechnic can be found in Alwis and O'Grady (2002).

Procedure

As part of the daily PBL sessions, students at Republic Polytechnic are required to reflect on the different aspects of their learning process and record their reflections in personal online journals. Utilizing this means, participants were asked to write a reflective essay on what they considered to be characteristics of good problems. The question posed to the participants was, "What is your perception of a good problem trigger to you and why? You can base your answer on any of the problems you have done so far."

Analysis

The participants' responses were compiled and reviewed to get an overview. Next, the data were analyzed using a text analysis software (TextSTAT) obtained from the weblink http://www.niederlandistik.fu-berlin.de/textstat/ (Huning, 2007). TextSTAT is a concordance soft-

ware that analyzes texts in ASCII/ANSI/ HTML/ Microsoft Office format. This software generates a list of all the words used in a document and counts the frequency of the words. The central idea in using the software was to break down the data into individual words. These individual words were then grouped together manually based on semantic similarities to identify problem characteristics. There are two points to consider in using this method of content analysis. One is the common assumption that the more frequently a word is mentioned, the more important the word is. With respect to this, Weber (1990) warned that it is possible to have a single idea or theme being represented by more than one word. Hence, we preferred to consider a group of words underpinning a particular theme of problem characteristics rather than single words to measure the significance ascribed. To this end, we categorized words of similar meanings into the themes based on conceptual closeness or synonymy and measured the frequency percentages of the group of words supporting the various themes of problem characteristics. Another possibility is that a single word can have a multitude of meanings. For instance, the word "like" could imply "comparison" or "resemblance." On the other hand, it could also mean "interest." Hence, it is important to consider the contextual use of the words. An advantage in using the TextSTAT software is that it has the function to select a particular word and display all the sentences containing the selected word. This facility in the textSTAT software allowed us to validate the contextual use of the words and include only the relevant occurrences. The underlying assumption in our content analysis is that the most frequently mentioned theme is of greatest concern to the students. This is in line with Weber's (1990) suggestion that it is preferable to consider words in categories than single words for content analysis (Cohen, Manion, & Morrison, 2007).

Figure 1 contains the complete response from participant 5 and table 1 shows how the data were coded. The Word document of the excerpt in figure 1 was processed by the textSTAT software. The software generated a frequency list of 319 words sorted out in descending order. A portion of the most frequent words is shown in table 1.

From the list generated, grammatical connectors and words deemed not to be associated with the theme of problem characteristics were excluded. Words that were associated with the theme of problem characteristics were then checked for contextual validity using the "Identify all sentences containing a specific word" function in the textSTAT software. This resulted in a list words associated with the theme of problem characteristics. For instance, when analyzing the frequency list in table 1, grammatical connectors such as "the," "to," and "it" were excluded first. Next, words such as "interesting," "difficult," "time," "think," "easy," "like," and "prefer," which were considered to be relevant to the theme of problem characteristics, were checked for contextual usage and selected. Following that, we went through the selected words manually to identify patterns and thus prominent themes. Words presumed to have similar meanings that refer to a specific aspect of problem characteristics were grouped together. From the list in table 1, the emergent themes were "problem interest" (interesting), "problem difficulty" (difficult, easy), "problem stimulating

Figure 1. Essay response by participant 5.

Personally I feel that a good problem trigger should be something interesting yet easy for us to understand. I would like it to be interesting so that I would not get bored while researching for the information. Besides that, it would be good for it to be slightly difficult as what is the use of a problem trigger if it doesn't trigger the mind and make us think out of the box. I don't prefer problem triggers that are too easy and straightforward because it just seems too easy to be true and we might finish our task too fast. Thus not making full use of the time given from the 2nd breakout till the 3rd meeting. Nevertheless, I do not prefer them to be too difficult because at times the topic that we need to touch on is quite a lot yet there is not much time to research and comprehend the findings before presenting. There was a trigger which I think is interesting and all of the above. It was a problem trigger from one of the biochemistry lessons (last semester). The problem trigger was in a form of a riddle. To me it was fun and interesting, as we need to crack our head to solve and understand the problem trigger. It goes like this:

"Thin or brawn
Men flex them with valor
Women have it permed and straightened,
For more than a dollar
Acrylic is out
Manicures are in
All the above
Are made of the same thing
Some soft
Others hard like pine
Take away their differences
What will you find?"

I feel that if problem triggers would be interesting it would give us the drive to do work/research. Furthermore if it is difficult to a certain extent, it will enable us/me to think hard and at the same time have a better discussion within the team and class.

Table 1. List of words generated by textSTAT software for response by participant 5.

Word	Frequency	Word	Frequency	Word	Frequency
the	17	that	6	Difficult	3
to	12	is	6	Time	3
it	10	would	5	Think	3
and	10	interesting	5	For	3
a	10	too	4	Easy	3
trigger	7	was	4	Like	3
be	7	us	4	Feel	2
problem	7	not	4	prefer	2
of	7	if	3	because	2
I	7	we	3	our	2

critical reasoning (think)," and "problem promoting self-directed learning" (time). In this manner, a total of eleven problem characteristics were identified from the analysis (table 2). Upon categorization, we went through the participants' complete responses once again to check if any other problem characteristics had been excluded and examine if meaningful references to these characteristics could be found in the participants' responses.

To answer the second question on which of these problem characteristics were perceived by the students to be the most important, the frequency percentages of words associated with the problem characteristics were computed (table 2). The problem charac-

Table 2. Key characteristics of problems for PBL.

A problem should…	Words used by students	Frequency of words used	Ranking of importance*
lead to learning issues	learn, issues, facts	23.8%	1
trigger interest	interesting, like, capture	11.5%	2
be of suitable format	phrase, picture, sentence	10.9%	3
stimulate critical reasoning	thoughts, ideas, logic	10.2%	4
promote self-directed learning	research, explore, tackle	10.0%	5
be of suitable clarity	obvious, clear, understand	7.3%	6
be of appropriate difficulty	easy, difficult, hard	7.1%	7
enable application or use	apply, world, use	7.0%	8
relate to prior knowledge	know, remember, background	6.7%	9
stimulate elaboration	elaborate, brainstorm, discuss	3.6%	10
promote teamwork	team, class, together	1.9%	11

*According to scale of importance from 1 to 11, 1 being the most important.

teristic with the highest frequency percentage was considered to be the most important characteristic to students. Since it is possible that one student could have referred to a particular characteristic multiple times, thus skewing the overall rank of importance, we also counted how many students referred to the identified eleven problem characteristics at least once. The later analysis was carried out to verify if there was any consensus among students on the most important problem characteristic.

To answer the third question on what can be learned from the students on problems for PBL; students' responses were scrutinized to understand why they found the problem characteristics to be necessary or useful.

Results

Salient Problem Characteristics in Students' Perceptions

Essay responses from the 34 participants were analyzed using the textSTAT software. Of the total 6,580 words in the compiled document, only 994 words were deemed relevant to describing problem characteristics. These words were then categorized according to semantic similarities. A total of eleven problem characteristics were identified. They were 1) the extent to which the problem leads to the intended learning issues, 2) interest triggered by the problem, 3) format of the problem, 4) the extent to which the problem stimulated critical reasoning, 5) the extent to which the problem promoted self-directed learning, 6) clarity of the problem, 7) difficulty of the problem, 8) the extent to which the problem is relevant; that is applicable and useful, 9) the extent to which the problem relates to the students' prior knowledge, 10) the extent to which the problem stimulates elaboration, and 11) the extent to which the problem promotes teamwork. Overall, the results indicate that it is possible to identify a wide spectrum of problem characteristics based on students' perceptions. Figure 2 provides examples of references to the identified problem characteristics. These references support the content validity of the problem characteristics.

The Most Important Problem Characteristic to Students

To answer the question on which of these eleven characteristics were perceived by students to be the most important, we did two things: 1) we computed the frequency percentages of the various words associated with each problem characteristic (see table 2), and 2) we counted how many students in this study referred to the identified eleven problem characteristics at least once. Based on the frequency of words, problems leading to the intended learning issues was ranked first with 24% and problems promoting teamwork was ranked the last with only 2%. This seemed to be consistent with the number of students referring to these two characteristics (figure 3). Chi-square test showed that there were

Figure 2. Students' responses that refer to key problem characteristics.

1.   Problem should lead to the intended learning issues
"Some problem trigger tends to give a lot of words while some give a little. However, what I want to see is key words in the problem statement. They do not have the need to be so obvious so that students will be able to search for resources immediately. However, key words which will give the students hints or even guide them to another major keyword and eventually allow them to find the key concept." (Participant 28)

2.   Problem should trigger interest
"I would think that it is highly interactive and interesting when we are given problem statements that concern our everyday way of life." (Participant 1)

3.   Problem should be of suitable format such as length of text or use of visuals
"My definition of good problem trigger is firstly, it has to be straight forward, NO NO NO to long winded ones, as the word 'trigger' tells all. It is the start of morning, a good problem can trigger off enthusiasm, if it is long winded, honestly, it can kill off the learning spirit." (Participant 5)

4.   Problem should stimulate critical thinking
"My perception of a good problem trigger is one that actually gets you thinking. One that is 'not that obvious' but still not difficult to figure out what the problem is about." (Participant 17)

5.   Problem should promote self-directed learning
"Even though we complain that some of the problem triggers is difficult, I do think that is good, as difficult problem triggers activates our minds and we will not waste our time doing other stuff. Furthermore, when the problem is harder, we would always refer to it to make sure that we are not going off track. Easy ones might be neglected and at the end of the day, we may go too off track and learn things which are not related to the topic." (Participant 12)

6.   Problem should be of suitable clarity
"A good problem trigger must contain clue words of the topic being taught for the day. Even if it is without any help of the worksheet, at least we know what we had to learn." (Participant 11)

7.   Problem should be of suitable difficulty
"It would be good for the problem to be slightly difficult as what is the use of a problem trigger if it doesn't trigger the mind and make us think out of the box. I don't prefer problem triggers that are too easy and straight forward because it just seems too easy to be true and we might finish our task too fast. Thus, not making full use of the time given from the 2nd breakout till the 3rd meeting. Nevertheless, I do not prefer them to be too difficult because at times the topic that we need to touch on is quite a lot yet there is not much time to research and comprehend the findings before presenting." (Participant 5)

8.   Problem should enable application or use
"The problem must be crafted in such a way that students would think out of the box in order to solve the trigger. If there are a lot of possible solutions, compared to always having one method in solving the trigger, the problem trigger would then be as challenging as it could be thought of. Having the knowledge of the lesson and

solving is not enough. The students must be able to apply what they have learnt to their daily life. So that in future when students faced such problems in their workforce, they would be able to relate it to what they had learnt in school." (Participant 24)

9.   Problem should relate to prior knowledge

"Problem should also relate to the real world, so that students have a stake in solving the problem. If at all possible, the problem should be placed in a context with which students are familiar." (Participant 21)

10. Problem should stimulate elaboration

"The problem trigger must be crafted in such a way that it is clear cut, easy to understand and contains keywords which are crucial to the day's problem. This would enable us to quickly start to research and brainstorm about the various concepts and ideas of the day's lesson." (Participant 27)

11. Problem should promote teamwork

"Furthermore if it (problem) is difficult to a certain extent, it will enable us/me to think hard and at the same time have a better discussion within the team and class." (Participant 5)

no significant differences between the students' responses regardless of the class they belonged to ($p = .92$, degree of freedom = 10). Even though responses from only a small group of students ($N = 34$) were included, the general trend is supportive of the findings that the most important characteristic in students' perceptions is the extent to which the problem leads to the intended learning issues.

Figure 3. Number of students referring to key problem characteristics.
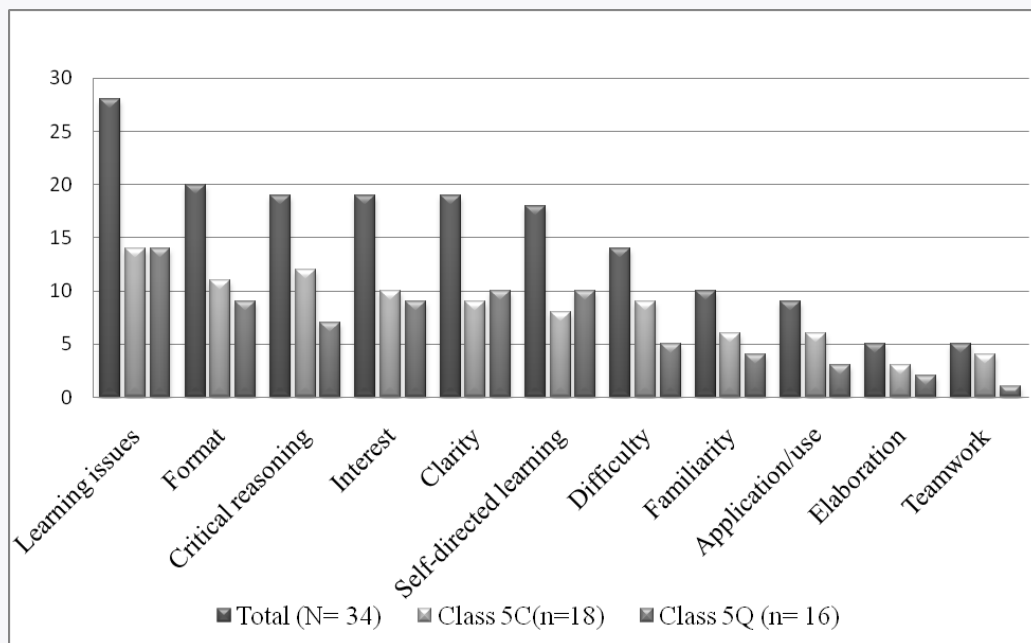
What Can We Learn from Students on Problems for PBL?

To understand why students considered each of these characteristics, we went through the students' responses in detail. Although there were no direct explanations in the students' responses, they still provided useful information. We had expected grades to be a key driving force in students' learning. Interestingly, students did not mention this; instead, they felt that problems should lead to purposeful learning. One participant wrote, "To me all problems are special. They represent different topics from the module. The purpose of the problem is to learn. . . . I believe that all problems are important as it contributes to my learning."

When we explored what students valued in learning through problems, their responses indicated that they valued problems which had clear references to the intended learning issues. Another way of looking at this is that learning issues that were not made clear in the problem were considered a waste of time. We presume that students were able to judge whether the problem had been effective in guiding them towards the relevant issues when facilitators summarized the day's learning and related the teams' discussion to the key learning objectives at the end of the problem. If the students deemed that they had managed to explore relevant issues pertaining to the problem, they concluded that the problem had been useful, whereas if they had veered off from the topics or learning issues intended by the problem, they felt that it was a waste. In other words, students valued learning for its relevance and not its own sake. One participant explained:

> Even though we complain that some of the problem trigger is difficult, I do think that that is good—as difficult problem triggers activate our minds and we will not waste our time doing other stuff. Furthermore, when the problem is harder, we would always refer to it to make sure we are not going off track. Easy ones (problems) may be neglected and we may go off track and learn things which are not relate to the topic. And that gives you a feeling that you have wasted the day searching for relevant information.

To formulate a problem that leads to the intended learning issues, students suggested several strategies. For instance, they felt that the problem should have a title that is related to the issues in the problem. The explanation was that the title could provide clues to the focus of the problem. There were also suggestions that the problem should contain key words. Students raised the point that when problems do not have sufficient clue words, other scaffolds provided by worksheets or facilitators may need to play a greater role in supporting their learning. In addition, it can be inferred that the lack of clue words in problem statements and insufficient scaffolding may result in unproductive searches and low quality work. The following quotation of a student's response illustrates this.

> A bad problem trigger is when there are no clue words or even worksheet for us to rely on. The problem that leaves a very bad impression would be Applied Chemistry—Body of evidence. Chemistry modules are my favourite but it can be horrible too. I spent almost 4 hours finding the concept in the topic. Actually, the topic was teaching us about stereochemistry. By the time, I totally had not time to comprehend the topic. A least my team managed to present a low quality power point.

Another suggestion was to use pictures in problem statements to provide additional information on the topic to guide the students to the intended learning issues. However, the student who suggested this was quick to note that the quality and content of the picture is crucial. The student wrote:

> Well, I feel that a good problem trigger must have a picture and some words. As a famous phrase: A picture speaks thousands words. I feel that sometimes if the problem statement has a picture, students can infer much from the picture. However, it depends on the quality and contents of the picture. For example, in microbiology, I can infer much from the problem statement regarding the water borne diseases. Even though it seems to be two normal pictures, to me, I seem to be able to know that the places are crowded and one of the pictures is showing people in a dry land. That let us know how come the government has to isolate the people to the dry land.

Students also felt that the use of other strategies such as analogies, examples, metaphors, and stories in the problem helped them towards identifying the relevant learning issues. Problem contexts based on familiar topics or those that built on previous problems were found helpful. Overall, it seemed that these various strategies influenced the clarity of the problem; that is, it was important that the problem be clear and comprehensible so that the intended learning issues could be identified. We define the use of problem title, keywords, pictures, analogies, examples, metaphors, and stories in the problem statement as the physical representation or format of the problem.

Other than the format of the problem, students also mentioned that the tasks involved in solving the problem (whether it involved interactive games or hands-on activities) influenced their interests. In addition, the difficulty of problems was suggested to have an influence over their interests in solving the problem and the extent to which the problem stimulated critical thinking and promoted self-directed learning. Participants felt that problems that were interesting and stimulating were able to engage them. The following quotation exemplifies this.

> For a good problem trigger, it should be easy to understand and it should be fun so that we will not feel bored. It should stimulate thinking and it should

> make us discuss more as a class or a team. Making it interesting will help us learn more as we will concentrate on doing the work and not on other things. For boring problems, we do not really look forward to the solving the problem. Instead we will not really look into the problem and just do the minimal work.

From the students' responses, it is possible not only to identify the characteristics of good problems, but it can also be inferred that students employ a decision-making strategy on whether and how they are going to work on the problem. A note of caution is that we have only presented a linear process here and this is merely a simplistic representation to help us understand which factors need to be considered in designing problems. It seems that when presented with a problem, students are first drawn to the problem format. For instance, they took note of subtleties such as the length of the problem, whether the problem included an informative picture, or if it involved interactive games. As mentioned earlier, the problem format seemed to affect the students' interest and willingness to engage in solving the problem. Next, students assessed the clarity of the problem and if they could comprehend what the problem required them to do. If students were not able to comprehend the problem and sufficient scaffolds such as facilitation were not available, they perceived minimal learning opportunities. The clarity of the problem seemed to be related very closely with the students' ability to identify the intended learning issues. Then, students evaluated the difficulty level of the problem and decided if they wanted to work the problem, to what extent, and how they wanted to approach the problem. This could be based on time and resource availability, how familiar they were with the subject, and what learning issues they wanted to focus on.

In sum, the students' responses offered various strategies to design problems that would allow them to learn in a PBL environment. Looking at the various responses and based on the suggested roles of the eleven characteristics, we recommend classification of the eleven characteristics into two groups: "features" or "functions." Features refer to characteristics that are the design elements of the problems. Characteristics such as problem format, clarity, familiarity, difficulty, and relevance (application and use) are the design elements of problems. On the other hand, functions refer to the potential or desired outcomes resulting from working on the problems. Of the eleven identified characteristics, the extent to which the problem stimulates critical reasoning, promotes self-directed learning, stimulates elaboration, promotes teamwork, stimulates interest, and leads to the intended learning issues are such functional properties. In a way, these functional characteristics are reflective of the five principles of constructivist learning and the objectives of PBL (Mayer, 1999; Savery & Duffy, 1995). Figure 4 shows the classification of the proposed feature and function characteristics.

Figure 4. Function and feature characteristics of problems.
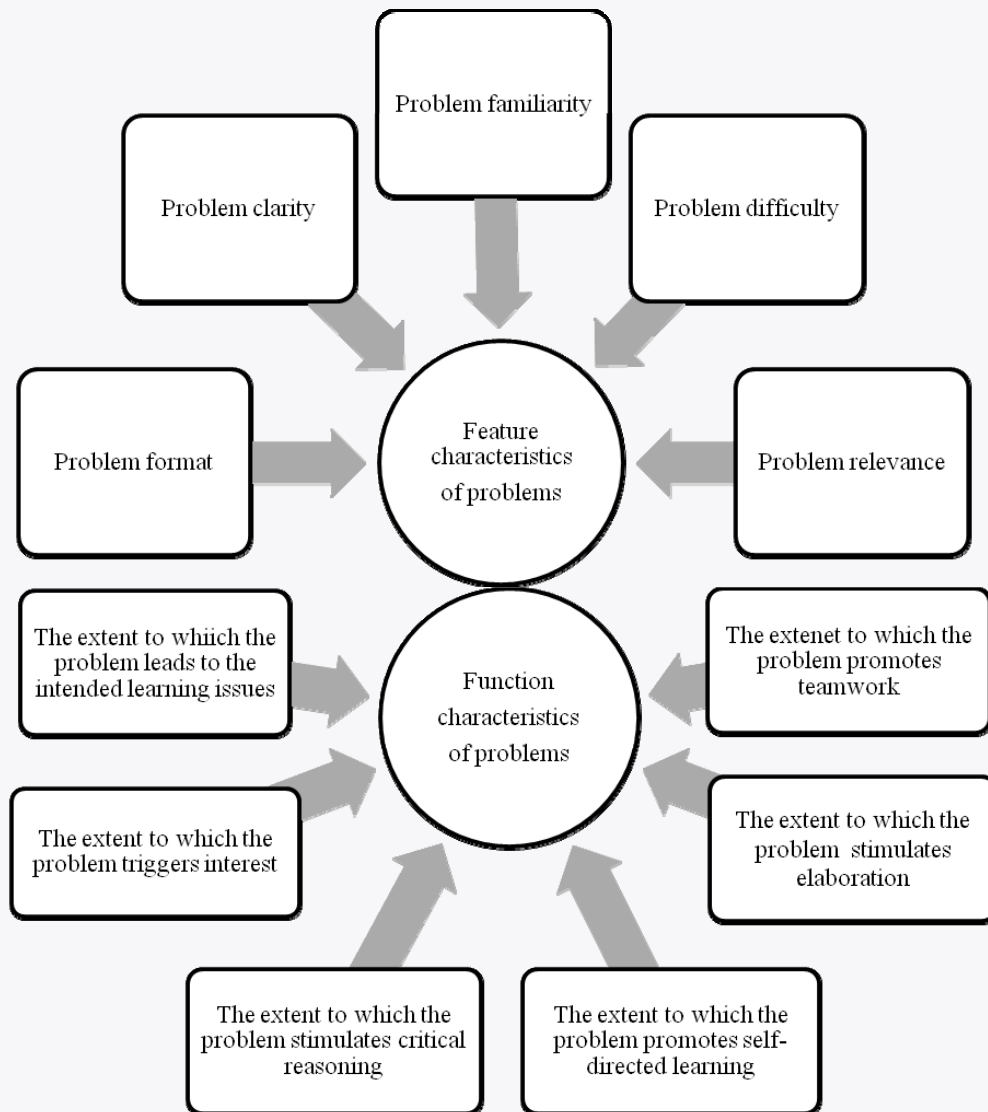
Discussion

This study investigated students' perceptions of the characteristics of good problems used in PBL, based on their experiences. The specific research questions were 1) which are the salient characteristics of PBL problems in students' perceptions? 2) which of these salient characteristics were perceived by the students to be the most important? and 3) what can we learn from students on problems for PBL? To this end, 34 second-year students from PBL curricula were asked to reflect in their e-journals on what they considered as characteristics of good problems. Text analysis of their responses, based on semantic similarities, resulted in the identification of eleven problem characteristics.

A comparison of the eleven problem characteristics from this study with those in the PBL literature (Des Marchais, 1999; Dolmans et al., 1997; Shaw, 1976) showed that the students identified similar characteristics. Table 3 presents a comparison of students' perspectives from this study with other empirical studies (e.g., Des Marchais, 1999), and theoretical guidelines (e.g., Dolmans et al., 1997). This relationship could be possibly because the students are constantly exposed to constructivist views during their PBL curricula. Hence, they may align their beliefs with the principles of constructivist learning (i.e., that learning occurs as a result of engaging in self-directed learning as well as collaborative work to find solutions to authentic problems, which results in gain in their content knowledge, and interest)(Savery & Duffy, 1995). As to whether students associate these principles in practice, Loyens, Rikers, and Schmidt (2007) showed that students in PBL curricula do espouse these constructivist assumptions.

Comparing the eleven characteristics from this study with Des Marchais's list of nine characteristics (1999), we can see that the students identified all of the nine problem characteristics cited by the experts. In addition, the students identified problem characteristics such as problem format, problem difficulty, and the extent to which the problem stimulates discussion and promotes teamwork, which were not mentioned by the experts. More noticeably, the students differed from the experts in the ranking of the problem characteristics. For instance, the experts in Des Marchais's study (1999) identified the two most important criteria to be 1) the extent to which the problem stimulates thinking or reasoning and 2) the extent to which the problem leads to self-directed learning in the students. However, the students in this study identified the extent to which the problem leads to intended learning issues as the most important characteristic.

An explanation for the differences observed could be the dissimilar roles played by the experts and students. Hence, their expectations of the quality of problems could be different. In line with this are studies which show discrepancies between the students' and tutors' perceptions of PBL. For instance, Zanolli, Boshuizen, and De Grave (2002) showed that students and tutors differed in their ratings on several aspects of PBL. In general, students placed higher importance than the tutors on issues associated with tutorial group functioning in PBL and the frequency of occurrence of these issues. What this means is that students' experiences with PBL could be different from that which is perceived by the tutors.

Another possibility could be that the objectives and implementation of PBL curricula in Rouen University and the Polytechnic in this study are different (Des Marchais, 1999). While Des Marchais's (1999) study was conducted in a medical university, the present study was conducted in a polytechnic, which employs PBL across all modules. Schmidt, van der Molen, Te Winkel, and Wijnen (2009) pointed out that the implementation of PBL varied across educational institutions, depending on the objectives of PBL, and proposed categorizing the various versions of PBL into three types. Type I PBL focuses on informa-

Table 3. Overview of problem characteristics from various studies.

11 criteria This study (Ranked by importance indicated by the prefix) Problem should…	9 criteria by Des Marchais (1999) (Ranked by importance indicated by the prefix) Problem should…	7 principles by Dolmans et al. (1997) (No ranking)	8 criteria by Schmidt (1985) (No ranking)	5 features by Shaw (1976) (No ranking)
1. Lead to learning issues	5. Lead to discovery of learning objectives	Should match one or more of the faculty objectives Problem to encourage integration of knowledge	Learning output	Solutions multiplicity
2. Trigger interest	6. Arouse curiosity and interest	Enhance students' interests	Intrinsic interest	Intrinsic interest
3. Be of suitable format				
4. Stimulate critical reasoning	1. Stimulate thinking, analysis and reasoning			
5. Promote self-directed learning	2. Initiate self-directed learning -	Stimulate self-directed learning	Time on task	
6. Be of suitable clarity	9. Contain appropriate medical analytical vocabulary			
7. Be of appropriate difficulty				Difficulty

8. Enable application or use	7. Be on topics related to public health 8. Consider a global perspective	In context that is relevant to future work		
9. Relate to prior knowledge	3. Relate to previous basic knowledge 4. Be proposed in a realistic context / Relate to previous basic knowledge	Adapt well to students' prior knowledge Relevant to basic concepts in clinical context	Familiarity / Prior knowledge	Familiarity
10. Stimulate elaboration		Stimulate students to elaborate		
11. Promote teamwork				Cooperation requirements

tion processing and is founded on the cognitive psychology principles of mental-model construction. Type II PBL is process oriented, focusing on problem-solving skills such as clinical reasoning, and type III PBL focuses on learning skills that help students learn how to learn. As the PBL curriculum in Des Marchais's study (1999) was a medical context, it is possible that it focused more on problem-solving skills, and was of type II PBL. In contrast, the institution involved in this study has adopted PBL across its curricula and focused more on knowledge construction as in type I PBL. Although reasonable, this postulation needs to be examined further. One way to overcome this difficulty in future studies will be to compare the perspectives of students and tutors from the same institution or the same type of PBL curricula. Understanding the differences between students' and tutors' perceptions will be important in interpreting the two groups' evaluations of modules or programs.

The Most Important Problem Characteristic to Students

Results from this study indicated that the most important characteristic to students is the extent to which the problem leads to the intended learning issues. This is reflected by two different methods of analysis: 1) by counting the frequency percentage of words associated with problem characteristics and 2) by counting the number of students mentioning a problem characteristic. This result is in line with the findings from an earlier study by

Schmidt (1985), which showed that students rated the most important characteristics to be the amount of knowledge gained from working on the problem. Taking a different perspective and assuming that the most vital characteristic of problems are likely to be cited by most if not all the various studies, we can conclude from table 3 that the characteristic of problems leading to the intended learning issues is indeed critical in defining the quality of PBL problems. Therefore, it is reasonable to infer that this characteristic is of high importance to the quality of problems. A possible reason for this could be the significance attributed to the construction of new knowledge in PBL (Mayer, 1999).

The Least Important Problem Characteristics to Students

The least referred problem characteristics by students in this study were the extent to which the problem stimulated elaboration and promoted teamwork. Interestingly, the experts in the Rouen Delphi study (Des Marchais, 1999) did not cite these two characteristics at all. Again, it is likely to be the result of the different roles played by the students and experts. This stresses the need for further studies to probe for both the students' and tutors' perspectives. In a way, these characteristics can be seen to be a reflection of the constructivist learning principle that learning takes place during collaboration (Savery & Duffy, 1995). A possible explanation for the low importance accorded to these problem characteristics could be that they are associated more with the tutor than with the problem due to the element of social interaction. These findings indicate that even though one of the key objectives of PBL is collaborative learning, problem designers may not be giving much consideration to this aspect. This raises the question of whether it is possible to design problems that promote collaborative learning. From the students' responses, it can be noted that problems that are interactive or those that involve hands-on activities and problems that require multiple perspectives promote collaborative work.

Other Salient Problem Characteristics in Students' Perceptions

Of the remaining characteristics, the fourth characteristic is the interest triggered by the problem. This characteristic is reflective of the underpinning principles of constructivist learning that the learning process should trigger students' interest (Mayer, 1999; Savery & Duffy, 1995). Gijselaers and Schmidt (1990), Schmidt and Gijselaers (1990), and van Berkel and Schmidt (2000) showed that the quality of problems has a positive influence on students' interest and learning. There are several other studies that showed that group discussion of the problem positively influences students' intrinsic interest in the subject matter (e.g., De Volder et al., 1986a, 1986b). Soppe et al. (2005) showed that familiar problems triggered more interest. Thus, this problem characteristic seems to be important in PBL.

The fifth characteristic is that problems should relate to students' prior knowledge. This can also be defined as familiarity of the problem in terms of both content and context. This problem characteristic relates to the cognitive psychology principles that activation

of prior knowledge in a collaborative group is needed to coconstruct new knowledge. Several studies supported the notion that prior knowledge strongly influences learning (Anderson, 1990; Dolmans, Wolfhagen, & Schmidt, 1996; Mamede, Schmidt, & Norman 2006; Norman &Schmidt, 1992; Schmidt & Boshuizen, 1990; Soppe, et al., 2005).

The sixth characteristic, clarity of the problem, can be defined as the extent to which the problem is comprehensible and transparent to students. The students' responses support the idea that this characteristic has a close association with the extent to which the problem leads to the intended learning issues. Students in this study suggested a number of ways to improve the clarity of the problems. For instance, they suggested using a catchy and informative problem title and using key words, analogies, examples, metaphors, stories, and informative pictures in the problem statement. These suggestions are similar to what Mayer (1999) proposed for instructional design. Mayer suggested that techniques such as using headings, providing a summary of information, or including additional questions and statements in instructional design can help students identify the important learning issues.

According to Verkoeijen, Rikers, Te Winkel, and van der Hurk, (2006), the specification of goals in the problem can influence the level of problem clarity. They showed that while specification of goals in a problem resulted in generation of more learning issues (quality and quantity) in the discussion phase, a goal-free version of the same problem had the advantage over the goal-specified problem during the reporting phase; the goal-free problem led to more quality and quantity of learning issues than the goal-specified problem. In addition, this study revealed that the goal-free problem had a positive influence on the study time, number of articles read, and time used for the reporting phase. Congruent with this, findings from our present study showed that problems that were not clear required students to spend more time in searching for relevant information. Interestingly, the students felt that the excessive time spent was futile, as their searches were found to be unrelated to the intended learning issues. More importantly, the unproductive searches seemed to negatively affect their interest and learning. What this tells us is that even though we might expect students to consider learning outside the intended learning issues as beneficial, students' opinion differed from this; students valued learning what was intended for them. Hence, it is worth exploring not just the quality and quantity of learning issues that are brought up by students when they work on problems but also whether students are able to achieve the intended learning issues. Students' responses also indicated that problems that were not sufficiently clear demanded them to rely on supportive scaffolds such as worksheet questions and facilitators. Therefore, scaffolding could also be considered when designing problems.

The seventh characteristic, format of the problem, is characterized by the physical representations of the problem such as whether the problem is in text format, if it includes an illustration, and whether it is short or long. Students' responses on this characteristic

indicated that the format of the problem has an influence on the interest triggered. This is in line with cognitive load theory which suggests that design of instructional materials need to suit our thinking processes. According to the cognitive load theory, the format of instructional materials influences the interest in learning and the efficacy of a learning environment (Hoffler & Leutner, 2007). Cognitive loads are classified into three types, namely, intrinsic, extraneous, and germane. The cognitive load of concern when considering the format of the problem can be said to be the extraneous cognitive load, which refers to the working memory load that learners experience as they interact with the instructional material. To illustrate extraneous cognitive load, Clark, Nguyen, and Sweller (2006) used the example of explaining what a square is. A square can be explained either visually using a picture or verbally by description. In this case, the visual representation of the square is likely to be more easily understood and therefore is of lower extraneous cognitive load. This also suggests that understanding the students' learning styles is critical to designing effective problems. Learners in general can be classified as visual, auditory or kinesthetic oriented. Therefore, it is pertinent that problem designers consider students' learning styles and the extraneous cognitive load associated with problem designs to maximize the potential of the problems. It will be valuable to find out empirically how the format of problems engages students.

The eighth characteristic that students referred to is problem difficulty. Contrary to our belief that difficult problems are not desirable, students' opinions indicated that difficult problems may not be bad for the students' learning. One participant noted,

> It would be good for the problem to be slightly difficult as what is the use of a problem if it doesn't trigger the mind and make us think out of the box. I don't prefer problems that are too easy and straightforward because it just seems too easy to be true and we might finish our task too fast. Thus, not making full use of the time given from the 2nd breakout till the 3rd meeting. Nevertheless, I do not prefer them to be too difficult because at times the topic that we need to touch on is quite a lot yet there is not much time to research and comprehend the findings before presenting.

From the student's response, we can deduce that problem difficulty is associated with the availability or use of time and resources. This is a slightly different way to look at the concept of problem difficulty. Although Jonassen and Hung (2008) and Jacobs et al. (2003) have attempted to define and validate the concept of problem difficulty, these existing studies did not provide sufficient clarification on students' perceptions of problem difficulty. Hence, this problem characteristic remains elusive and further research is needed to understand how and why it effects students' interest and learning.

The ninth characteristic raised by the students is the extent to which the problem is perceived relevant, that is, applicable or useful. PBL is founded on the principle that stu-

dents not only acquire knowledge but also that they know how to apply this knowledge in real situations. Thus, use of authentic contexts is recommended for PBL (Savery & Duffy, 1995). Research on learning showed that information learned in context is better recalled and retained (Brown, Collins, & Duguid, 1989). In addition, problems that are perceived to be relevant are likely to engage students in the learning process, contributing to their learning. For instance, Araz and Sungur (2007) showed that task value was one of the factors which had both direct and indirect effects on achievement in genetics. Hence, problem designers would need to consider not just the content of the problem, but also the relevancy.

The tenth and eleventh characteristics of problems are the extent to which the problem promotes self-directed learning and stimulates critical reasoning. These characteristics are also reflective of constructivist principles (Savery & Duffy, 1995) and focus on students' problem-solving skills and learning to learn skills (Mayer, 1999). Therefore, these characteristics are likely to be more highly regarded in institutions which adopt type II and type III PBL (Schmidt et al., 2009). PBL has been shown to have an influence on students' critical reasoning (Albanese & Mitchell, 1993) and self-directed learning (Blumberg & Michael, 1992). This influence could be the result of several variables such as the quality of problems, the role of tutors, and the learning environment. Looking at the various variables at the same time may result in confounding results. Therefore it may be useful to look at the variables one at a time. For instance, future research could investigate how problem quality influences critical reasoning and promotes self-directed learning. More specifically, we can explore how a particular problem characteristic such as problem difficulty influences critical reasoning and self-directed learning.

Classification of the Eleven Characteristics as Feature and Function Characteristics

After reviewing the eleven characteristics, we determined that they can be classified as either features or functions based on their roles. Even though existing studies have identified various characteristics of problems, these are not classified further. The exception is Hung's classification of design elements as core and process components (Hung, 2006), which categorizes elements that lead to conceptual learning and processes in PBL. Our classification of the problem characteristics as feature and function characteristics differs in the sense that it attempts to identify characteristics that can be manipulated and considered in designing and evaluating the problems to enhance students' learning. This is elaborated in the following sections on implications for problem designing and problem evaluation. In addition, we also propose that that the feature characteristics can be manipulated to bring about an effect on the functional characteristics.

Implications for Problem Design

Considering the eleven characteristics that students associate with good problems and how students approach a given problem, we propose that problem designers need to attend to the feature characteristics of problems while keeping the function characteristics in mind. For instance, problem designers could manipulate problem clarity by using catchy titles, clue or key words, analogies, metaphors, stories, and pictures in the problem design to guide students in their learning. As clarity is associated with comprehension, we recommend that problem designers consider students' language abilities and prior knowledge. Problem designers should also find out about the students' learning styles so that the format of the problem is selected appropriately to cater to different learning styles (visual, auditory, or kinesthetic learning). Since students' perceptions of problem difficulty and willingness to work on the problem are likely to depend on the learning issues, problem familiarity level and applicability should be considered. Problem designers need to also think about what knowledge and skills they expect students to achieve (intended learning issues) and what prior knowledge students are likely to have and to select an appropriate and authentic context to frame the learning issues. When selecting the context of the problem, problem designers can choose contexts familiar to students or contexts that are likely to be useful or relevant in other modules or future work. In essence, problem designers need to consider the five feature problem characteristics (problem format, clarity, familiarity, relevance and learning issues) in designing the problems.

Implications for Problem Evaluation

The results of this study add further support to the existing understanding that the extent to which the problem leads to the intended learning issues is an important indicator of the problem effectiveness. In addition, the results add other characteristics (such as the extent to which the problem stimulates critical reasoning, promotes self-directed learning, stimulates elaboration, promotes teamwork, or stimulates interest) that need to be considered in evaluating the effectiveness of problems. The functional characteristics of problems are likely to serve as appropriate indicators of problem effectiveness as these characteristics represent the objectives of PBL. Therefore, measuring these characteristics can be used to indicate the extent to which problems play a role in the effectiveness of PBL. In support of this proposition is the study by Munshi, El Zayat, and Dolmans (2008), which developed a rating scale to assess the effectiveness of 12 problems from a PBL curriculum. The results from their study demonstrated that problems stimulating thinking, problems enhancing analysis and reasoning, and problems stimulating self-directed learning can be used to measure the effectiveness of problems. However the validity and reliability of the rating scale was not tested. To evaluate the effectiveness of problems, future studies could investigate how the feature characteristics influence the functional characteristics of problems.

Limitations

There are a number of limitations to this study. One limitation is that the students' responses were used to derive the characteristics of the problems for PBL. Hence the study is limited by students' range of vocabulary. Moreover, the risk is that if students are not able to recognize the different characteristics of problems, they will not be able to mention these concepts, thus increasing the chance of the students overlooking these characteristics. Nevertheless, results from this study show that students participating in this study were able to use words that match with characteristics identified by experts. The second limitation is that tutors' perceptions (on problems used in PBL) from the same institution that adopts a similar type of PBL (Schmidt et al., 2009) were not included. This presents itself for further work. The third limitation is that the students were not given concrete sample problems to refer to. Hence, they could have mentally referred to different problems. In future studies, students could be given concrete sample problems to refer to. Fourth, this study was carried out with experienced second-year PBL students. Loyens et al. (2007) showed that students in different academic years differ in their conceptions of PBL. Hence, it is possible that students from different academic years may differ in their perceptions and this needs further work.

Conclusions

In sum, this study has taken the first steps in identifying the various characteristics associated with good problems in PBL. A total of eleven characteristics were found to be associated with good problems in students' perceptions. Of these, the most important characteristic was the problem leading to the intended learning issues. Based on the students' responses, we propose that the eleven problem characteristics can be classified into feature and function characteristics. The implication of this categorization is that problems can be designed by manipulating the feature characteristics of the problems while keeping the function characteristics in mind. The function characteristics are likely to be useful in evaluating the effectiveness of problems. This research gives rise to future research work of going beyond identifying the characteristics to examining the role of each problem characteristic and unraveling the relationships among the various problem characteristics in influencing students' learning.

Acknowledgments

References

Albanese, M., & Mitchell, S. (1993). Problem-based learning: A review of the literature on its outcomes and implementation issues. *Academic Medicine*, *68*, 52-81.

Alwis, W. A. M., & O'Grady, G. (2002, December). *One day-one problem: PBL at the Republic Polytechnic*. Paper presented at the 4th Asia-Pacific Conference on PBL, Hatyai, Thailand.

Anderson, J. R. (1990). *Meaning-based knowledge representations*. New York: Freeman.

Araz, G., & Sungur, S. (2007). The interplay between cognitive and motivational variables in a problem-based learning environment. *Learning and Individual Differences, 17*(4), 291-297.

Blumberg, P., & Michael, J. A. (1992). Development of self-directed learning behaviours in a partially teacher-directed problem-based learning curriculum. *Teaching and Learning in Medicine, 4*(1), 3-8.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*, 32-42.

Clark, R., Nguyen, F., & Sweller, J. (2006). Efficiency in learning: Evidence-based guidelines to manage cognitive load. San Francisco: Pfeiffer.

Cohen, P. A. (1981). Student ratings of instruction and student achievement: A meta-analysis of multisection validity studies. *Review of Educational Research, 51*, 281-309.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). Abigdon, UK: Routledge.

De Volder, M. L., Schmidt, H. G, Moust, J. H. C., & De Grave, W. S. (1986). **Problem-based learn**ing and intrinsic motivation. In J. H. C. van der Berchen, T. C. M. Bergen, & E. E. I. de Bruyn (Eds.), *Achievement and task motivation* (pp.128-134). North America: Swets (PA4).

De Volder, M. L., Schmidt, H. G., Moust, J. H. C., & De Grave, W. S. (1986). **Motivation and achieve**ment in cooperative learning: the role of prior knowledge. In J. H. C. van der Berchen, T. C. M. Bergen, & E. E. I. de Bruyn (Eds.), *Achievement and task motivation* (pp. 123-127). North America: Swets (PA4).

Des Marchais, J. E. (1999). A Delphi technique to identify and evaluate criteria for construction of PBL problems. *Medical Education, 33*(7), 504-508.

Dolmans, D. H. J. M., Schmidt, H. G., & Gijselaers, W. H. (1995). The relationship between student-generated learning issues and self-study in problem-based learning. *Instructional Science, 22*(4), 251-267.

Dolmans, D. H. J. M., Snellen-Balendong, H., Wolfhagen, I. H. A. P., & van der Vleuten, C. P. M. (1997). Seven principles of effective case design for a problem-based curriculum. *Medical Teacher, 19*(3), 185-189.

Dolmans, D. H. J. M., Wolfhagen, I. H. A. P., & Schmidt, H. G. (1996). Effects of tutor expertise on student performance in relation to prior knowledge and level of curricular structure. *Academic Medicine, 71*(9), 1008-1011.

Gijselaers, W. H., & Schmidt, H. G. (1990). Development and evaluation of a causal model of problem-based learning. In Z. H. Nooman, H. G. Schmidt & E. S. Ezzat (Eds.), *Innovation in medical education: An evaluation of its present status*. New York: Springer Publishing.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235-266.

Hoffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction, 17*(6), 722-738.

Huning, M. (2007). TextSTAT (Version 2.7). [Software].

Hung, W. (2006). The 3C3R model: A conceptual framework for designing problems in PBL. *Interdisciplinary Journal of Problem-Based Learning, 1*, 55-77.

Jonassen, D., & Hung, W. (2008). All problems are not equal: Implications for problem-based learning. *2*(2), 6-28.

Jacobs, A. E. J. P., Dolmans, D. H. J. M., Wolfhagen, I. H. A. P., & Scherpbier, A. J. J. A. (2003). Validation of a short questionnaire to assess the degree of complexity and structuredness of PBL problems. *Medical Education, 37*(11), 1001-1007.

Loyens, S. M. M., Rikers, R. M. J. P., & Schmidt, H. G. (2007). Students' conceptions of distinct constructivist assumptions. *European Journal of Psychology of Education*, *12*, 179-199.

Mamede, S., Schmidt, H. G., & Norman, G. R. (2006). Innovations in problem-based learning: What can we learn from recent studies? *Advances in Health Sciences Education, 11*, 403-422.

Majoor, G. D., Schmidt, H. G., Snellen-Balendong, H., Moust, J. C. H. & Stalenhoef-Halling, B. (1990) Construction of problems for problem-based learning. In Z. Nooman, H. G. Schmidt & E.S. Ezzat (Eds.), *Innovation* (pp. 114-122). New York: Springer.

Mayer, R. H. (1999). Designing instruction for constructivist learning. In C. M. Reigeluth, (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (volume 2, pp. 141-160). Mahwah, NJ: Lawrence Erlbaum Associates.

Munshi, F. M., El Zayat, E. S. A., & Dolmans, D. H. (2008). Development and utility of a questionnaire to evaluate the quality of PBL problems. *South East Asian Journal of Medical Education, 2(2)*, *32-40.*

Norman, G. R., & Schmidt, H. G. (1992). The psychological basis of problem-based learning: A review of the evidence, *Academic Medicine, 67*, 557.

Savery, J. R., & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. *Educational Technology*, *35*(5), 31-38.

Schmidt, H. G. (1983). Problem-based learning: Rationale and description *Medical Education, 17*, 11-16.

Schmidt, H. G. (1985). *Attributes of problems for problem-based learning.* Unpublished manuscript. Maastricht, the Netherlands: University of Limburg.

Schmidt, H. G., & Boshuizen, H. P. A. (1990, April). *Effects of activation of prior knowledge on the recall of a clinical case*. Paper presented at the Meeting of the American Educational Research Association.

Schmidt, H. G., & Gijselaers, W. H. (1990, April). *Causal modeling of problem-based learning*. Paper presented at the Annual Meeting of the American Educational Research Association, Boston, MA.

Schmidt, H. G., van der Molen, H. T., Te Winkel, W., & Wijnen, W. H. F. W. (2009). Constructivist, problem-based learning does work: A meta-analysis of curricular comparisons involving a single medical school. *Educational Psychologist, 44,* 1-23.

Shaw, M. E. (1976). *Group dynamics*. New York: McGraw-Hill.

Soppe, M., Schmidt, H. G., & Bruysten, R. (2005). Influence of problem familiarity on learning in a problem-based course. *Instructional Science, 33*(3), 271-281.

van Berkel, H. J. M., & Schmidt, H. G. (2000). Motivation to commit oneself as a determinant of achievement in problem-based learning. *Higher Education, 40*, 231-242.

van den Hurk, M. M., Wolfhagen, I. H. A. P., Dolmans, D. H. J. M., & van der Vleuten, C. P. M. (1999). The impact of student-generated learning issues on individual study time and academic achievement. *Medical Education, 33*(11), 808-814.

Verkoeijen, P. P. J. L., Rikers, R. M. J. P., Te Winkel, W. W. R., & van der Hurk, M. M. (2006). Do student-defined learning issues increase quality and quantity of individual study? *Advances in Health Sciences Education, 11,* 337-347.

Weber, R. P. (1990). *Basic content analysis*. Newbury Park, CA: Sage.

Zanolli, M. B., Boshuizen, H.P., & De Grave, W. S. (2003). Students' and tutors' perceptions of problems in PBL tutorial groups at a Brazillian medical school. *Educational Health (Abingdon), 15*(2), 189-201.

Nachamma Sockalingam is Lecturer at the Teaching and Learning Centre, SIM University, Singapore. She was previously with the Centre for Educational Development, Republic Polytechnic, Singapore, where this research study was conducted.

Henk G. Schmidt is Professor of Psychology at Erasmus University, Rotterdam, the Netherlands. Presently he is the Rector Magnificus of this university.