An Event Model for the Application of Problem-based Learning/e-learning in Thermodynamics

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Abstract

Thermodynamics is an essential topic in Engineering education. Difficulties in teaching and learning thermodynamics are well known, and many efforts have been developed to improve the teaching of thermodynamic subjects. The solution of problems is the main task in Engineering education, and much effort must be carried out to describe strategies and standard procedures. Methodologies involving problem-based learning, group work, and e-learning appear very often as the best options to develop skills related to thermodynamics properly.

The objective of the present work is to describe a project involving a combined methodology of problem-based learning and e-learning in Applied Thermodynamics in the Chemical Engineering program at the Universidad Rey Juan Carlos (Móstoles, Madrid, Spain). Students solved proposed problems using Excel worksheets in a short time; the activity was carried out voluntarily, individually, and without the professor's help. Grades obtained in such activities were compared to grades from the standard methodologies involved in grading the subject (exams and seminar problems).

A stronger correlation was found between PBL/e-learning and exam grades than between seminars and exam grades, suggesting that working group activities are of limited value. The opinion of the involved students also favored the PBL/e-learning approach.

Keywords: problem-based learning, worksheet applications, thermodynamic calculations, chemical engineering.

1. Introduction

Chemical thermodynamics is a central topic in Chemical Engineering programs. Sandler [1] states that thermodynamics is central to the practice of chemical engineering and consequently to the education of a chemical engineer and highlights as main areas the study of phase equilibria, chemical equilibria, energy balance, and process yield. However, an opposite view is stated by Hawkes [2], who observed that equilibrium study is not important because engineering systems do not reach an equilibrium state. The texts commonly used in Chemical thermodynamics courses [3, 4, 5, 6, 7, 8, 9] cover such topics: equations of state, thermodynamic properties, energy functions, fugacity and activity, thermal cycles, phase equilibria, and chemical equilibria.

Difficulties in teaching and learning thermodynamics are widely studied [10]. Most students find the subject very difficult, theoretical, and far from real applications. Many techniques have been proposed [11] to overcome such difficulties and correctly develop the desired skills. According to Barrows [12], the primary skills to be acquired by the students using several methodologies are problem-solving, designing, interactivity, teamwork, and some thermodynamic concepts.

The main problem in the regular teaching of this material, and other engineering aspects, is related to the conventional pedagogy of “chalk and talk,” which has been described as ineffective compared to methods based on the problem or project-based learning (PBL). The latter has been fully described in several fields, such as medicine [12], artificial intelligence [13], and engineering [14]. A recent study [15] directly relates the PBL method to student motivation.

PBL can be further enhanced when the problem or project must be solved by a group of students better than by individuals. Students appear more motivated to cooperate with other students than to prepare for traditional exams or engage in problem-solving; the synergic effect and the cross-learning between them are clear [16]. Descriptions of how to develop group activities [17, 18] and evaluate them [19] can be found elsewhere. Also, the main advantages for the instructors have been described as the possibility of proposing more complex problems and reducing the number of problems to design and grade [20].

A third main improvement can be obtained using computer-based learning, which has been widely found to assist with teaching in the engineering disciplines [11, 21, 22, 23], though its use varies internationally [22]. Several strategies can be employed: the web, multimedia-ready packages, pedagogical software with ready applications, and developing programming skills. The last one can be considered an essential skill itself. However, engineering courses only sometimes cover programming learning well [24].

Recent reviews covering such methodologies, individually or combined, can be found in the literature [25, 26, 27, 28, 29].

Applied Thermodynamics is taken in the second year of the Chemical Engineering program at the Universidad Rey Juan Carlos (Móstoles, Madrid, Spain). The concepts covered are typical of Applied Chemical Thermodynamics courses (equations of state, thermodynamic properties, energy functions, fugacity and activity, thermal cycles, phase equilibria, and chemical equilibria), and the main texts are those referenced above [3, 4, 5, 6, 7, 8, 9].

The Applied Thermodynamics course at the Universidad Rey Juan Carlos does not include laboratory practical activities because such practical lessons are given later in an Integrated

Laboratory course, and this is one of the reasons why most students find thermodynamics a very theoretical subject, mainly focused on the description of models, equations, and concepts.

However, far from the pedagogy of "chalk and talk," some methodologies based on problem-based learning [14] were included in the subject. The main objective is the application of equations and models to solve problems and focus on the quantitative aspects included in the mathematical formulation. Consequently, the subject is highly focused on the numerical problem solution, which is covered in several pedagogical activities:

- Problems are proposed well in advance, and the professor presents their solution in regular master lessons after students try them on their own.
- Problems are proposed to be individually solved by the students in an "online test" whose solutions are recovered online, graded, and included in the qualification of the subject.
- Problem resolution in "seminar" sessions is a working group activity where students must solve problems and deliver the solutions at the end of the seminar; they are graded and included as a part of the qualification of the subject.

A great advantage would be obtained if such activities were combined with computer facilities, not only because of the simplicity in the grading but also because the programming tasks are good exercises for most students; when a student can make even a simple program, the outlined concepts are better understood, and the physical meaning is more evident [30, 31]. However, despite most students having followed the subject of Applied Informatics, they used to refuse the application of programming languages because of their lack of experience. Most activities must be considered free, out of the qualification system, and limited to using more accessible tools such as Excel. Such a point is not necessarily a limitation as some exciting applications were described to be carried out using a spreadsheet [32, 33].

This paper aims to describe the results obtained in a project carried out on the Applied Thermodynamic subject of the Universidad Rey Juan Carlos and focuses on combining problem-based learning strategies with programming tools to solve the proposed problems.

2. Methodology

2.1. Seminars on problem-based learning

As indicated above, the master class includes theoretical concepts and problem-solution lectures. Problems are previously proposed on a university internet platform called Virtual Campus, and students can practice their solutions before the lecture.

A different methodology is using PBL seminars where problem statements are distributed to students who form working groups and must solve the problem. Such activities are of short extension (about 2 hours), fit with the description of problem-based learning in engineering education [14], yield good results in the skill achievement described by Mulop [11], and take advantage of working in a group [16].

Seminars are interactive because students work in small groups, can use previously solved problems or textbooks, and can ask for help from the professors. Assistance and leadership of the professor are essential to ensure the right strategy for problem-solving, to help the groups with difficulties, to make the proper delivery time for each activity, and to validate intermediate calculated values for successful progress.

Students deliver the solutions at the end of the seminar, which is then corrected, graded (up to ten), and added as a part of the official qualification of the subject.

2.2. Problem-based learning by using computer facilities

The activity was the resolution of a proposed problem using Excel software. It was offered to all students of Applied Thermodynamics in the Chemical Engineering program as a voluntary activity and, consequently, apart from the official qualification. Each student attended, individually and voluntarily, for a short time, around thirty minutes, to the professor's office, and such an option was repeated every week with different problems according to the contents previously explained in the lectures of the master classes.

The students requested their appointment weekly in the available spaces. Four lecturers were involved in the project and committed one hour daily; thus, the maximum capacity was forty students a week. However, as a voluntary activity, the degree of participation was lower than such a limited value.

Figure 1 presents Problem 1 as an example of the proposed problems inside an Excel worksheet with several different sections:

- a) Cells of evaluation. The worksheet is connected to the professor`s sheet with the correct values; it detects whether the students' answers are correct and automatically gives the evaluation.
- b) The number of the problem and the main topic is indicated as a title, followed by a list of specific calculations to be carried out.
- c) Cells to be fulfilled by the student with the obtained solutions.
- d): The professor supplied all the required data to allow the student to refer to the corresponding cell.

Students can use the rest of the worksheet to develop their calculations or program the required equations in section c). As seen in the example, the same question is asked for three different systems to look for a better programming exercise useful for repeating calculations.

All the problems were formed by fifteen calculations, equivalent, and graded 0.67. The activity grade was the sum of the single calculations (up to ten).

This activity was conducted over nine weeks of the semester, and nine problems were proposed, covering several topics in the Applied Thermodynamics subject. Table 1 lists the detailed content of each issue, named P1 to P9, all designed similarly to Problem 1 described above.

2.3. Opinion survey

Student opinion was tested with an opinion survey given to students participating in the PBL activity. Students must indicate the degree of agreement from 0 to 10 (0: total disagreement, 10: total agreement) to five blocks of questions covering aspects of general evaluation, background and motivation, opinion about competencies acquired, dedication, and suggestions for further improvement. Table 2 lists the detailed questions.

3. Results

3.1. Participation and student performance

Figure 2 shows the total number of students participating in the proposed activities, and even though the number of participants was lower than expected, representing only 28% of the students in the subject, the results can be considered satisfactory, and 52% of the participating students repeated and completed several activities.

The value of the grade obtained (out of ten) for each proposed activity is presented in Figure 3 as a measure of the student's performance. Detailed analysis reveals how 70-90% of students pass the activity (grade over five) in P1, P4, P5, and P8 activities; such value decreases to 30-40% in P2, P3, P6, and P9, and in the case of P7, 100% of students failed the PBL.

Grades are relatively high and considered satisfactory considering that the available time is relatively short (thirty minutes), the problem-solving procedure is very different from that used in class, and the previous programming experience of the students is very limited. However, the main difficulty can be related to the specific problem, as in regular evaluation text, and not the methodology.

The proposed problems are solved individually without interaction with the lecturer. Consequently, such results are directly related to the student's individual ability.

3.2. Integration in the Applied Thermodynamic subject

Results of the activity are compared with those obtained in other activities that are involved in the qualification of the subject Applied Thermodynamics: seminars and exams, where problems are similar to those proposed in class during the course:

- Seminars: students solve problems in two hours, working in groups and with the lecturer's support if necessary. This kind of activity is proposed as training before exams.
- Exam: students must solve individually, without any possible communication, and with limited questions to the professor.

Table 3 lists aspects of the three involved methodologies to clarify points of difference and similarity.

All the grades considered are up to ten; as a reference, five is the required grade to pass the subject. Figure 4 shows individual grades obtained in the final exam versus the average qualification of the various seminars during the course about Applied Thermodynamics. Significantly, 40% of students reach exam grades lower than five, even when 96% obtain seminar grades above six. This result represents a drawback of the group activities and shows that many students obtain good grades because the group performance is achieved without a real understanding of the matter and shows low learning usefulness.

However, the correlation of individual exam grades with the results of PBL is different. Figures 5 a) and b) present the individual exam grades versus the number of PBL activities and the PBL grade obtained, respectively. Only 20% of the students who have realized at least one PBL do not reach five in the final exam, which falls to 8% for students who have undertaken more than one PBL. Only 10% of the students who obtained more than five in PBL problems failed the final exam, and most of the students with high grades in the PBL activities received similar results in the final exam problems.

3.3. Opinion survey and comments

The opinion of eighteen students who participated in PBL activities was tested with the opinion survey given in Table 3. Figure 6 plots the results obtained for each question.

The average grade of Block I (P1-P5) is eight. Students consider this activity interesting; they have learned how to solve these problems, and the proposed problems are adequate for the subject contents.

The average Block II (P6-P10) grade is seven, and, in general, students recognize that, despite the previous lack of knowledge of Excel or other computer tools (P6 y P7), they have been able in improve their ability to perform the problems in the final exam and gain a mastery of the subject (P9 and P10).

The Block III (P11-P15) average result is eight; the highest grade is for the question about whether PBLs have been an excellent complement to understanding the subject (P15), followed by that about motivation (P14) and improvement in Excel usage skill (P13).

The Block IV (P16-P20) average grade is 6.8; students consider that the extra time used in this project is useful (P20) and acknowledge that they have studied the subject every day (17). Nevertheless, most students think thirty minutes is not enough (P19).

The average Block V (P21-P24) result is 7.3. Students suggest repeating this activity every year and including other subjects (P21 and P22); however, they prefer to keep it as a voluntary activity, not increasing the difficulty and time involved.

4. Conclusions

Results of a straightforward educational project involving techniques of PBL/e-learning carried out in the Applied Thermodynamic subject of the Chemical Engineering program at the Universidad Rey Juan Carlos (Móstoles, Madrid, Spain) have been presented.

The methodology involved problem solutions using Excel worksheets, individually, without help, during a short time, voluntary and out of the official grade, and was very different from alternative problem solution activities.

Participation of the students was reasonable and higher than 30%, with most of them participating actively several times. Relatively good grades were obtained in the activity despite limited time and Excel experience.

A poor correlation was found between the exam grades and the group seminar grades, probably due to the misconception of the group working. However, a clear correlation was obtained between grades of the voluntary activity and exam grades, thus reinforcing the interest in individual, PBL, and computer activities.

The opinion of the students was checked using an evaluation test at the end of the activity calendar, and their opinion was very positive about such activities even when previous experience in programming or Excel was generally very limited.

5. Final remark: application in the classroom

This paper presented the procedure and results of an exploratory project. The results are promising, and the next step should be to apply that methodology to all students and include this activity's grade as part of the final grade. It would require a classroom with computer facilities, where every student develops, working on their own, the proposed activity. A different option would be to develop the activity online for a short time to prevent communication.

Probably grades will be lower than that obtained in the current project. Still, they will be representative of the actual performance of the students, and benefits can be better than that obtained by group activities.

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Table 1: List of proposed problems and detailed calculations covered.

Problem	Chapter	Content
P1	Volumetric properties	• Property estimation • Joback method
P2	Volumetric properties	• SRK equation of state • Parameters a, α, b • Mixing rules • Z and V_m determination • Pure components and mixtures
P3	Thermodynamic properties	• Residual properties • Changes in H and S
P4	Real gases	• Virial equation of state • Fugacity and fugacity coefficient for pure components
P5	Real gases	• Virial equation of state • Mixing rules • Fugacity and fugacity coefficient for mixtures
P6	Liquid phase	• Van Laar model • Activity and activity coefficient • Excess properties
P7	Liquid phase	• NRTL model • Activity coefficient
P8	Vapor-liquid equilibrium	• Pure component vapor pressure • Van Laar model • Activity coefficient • Isothermal vapor-liquid equilibrium calculations
P9	Vapor-liquid equilibrium	• Pure component boiling temperature • Van Laar model • Activity coefficient • Isobaric vapor-liquid equilibrium calculations

Table 2: Test to evaluate the activity by the students.

Block I: General evaluation of activity:
P1. Has it been interesting? P2. Have you learnt doing this activity? P3. Are PBL contents adequate for Applied Thermodynamics subjects? P4. Has been the PBL calendar suited to the development of the subject? P5. Has the activity been well organized?
Block II: Student background and motivation:
P6. Do you have experience in the use of Excel? P7. Have you used computing tools in others subject based on mathematics? P8. Have you participated by getting more grades? P9. Have you participated to improve your problem-solving ability like the final exam?
Block III: Competences acquired:
P10. Have PBLs improved your ability to understand the theory? P11. Have PBLs improved your ability to understand the procedure to solve problems? P12. Have PBLs improved your ability to work with Excel? P13. Have you been motivated to reach maximum grades in each PBL? P14. Do you think these PBLs have been a good complement to the subject?
Block IV: Student dedication:
P15. Have you prepared PBLs previously? P16. Do you think these PBLs are useful for studying the subject every day? P17. Have you needed much time to prepare for PBL? P18. Do you think 30 minutes is enough to solve PBLs? P19. Is the extra time used in preparing PBL useful?
Block V: Suggestions:
P20. Would you keep this activity every year in this subject? P21. Would you extend this activity to other subjects? P22. Would you make this activity obligatory for all students? P23. Would you increase the difficulty of PBLs and allow them to be carried out with more time?

Table 3: Comparison of several aspects of three methodologies

	Seminar	**Exam**	**PBL / e-learning**
Complexity/extension of problems (against solved in lectures)	Higher	Identical	Identical
Individual activity	No	Yes	Yes
Group activity	Yes	No	No
Help of lecturer	Yes	Some	No
Available time (h)	2	2	0.5
Voluntary	No	No	Yes
Part of the final grade	Yes	Yes	No
Computer facilities	Calculator	Calculator	Excel

Figures

a) b) c)

Qualification	PROBLEM 1 Estimate properties for corresponding compounds		Solution
0	1	Melting T for 2,3,4 tri methyl hexane	
0	2	Boiling T for 2,3,4 tri methyl hexane	
0	3	Critical T for 2,3,4 tri methyl hexane	
0	4	Critical P for 2,3,4 tri methyl hexane	
0	5	Critical V for 2,3,4 tri methyl hexane	
0	6	Melting T for 1-hexanol	
0	7	Boiling T for 1-hexanol	
0	8	Critical T for 1-hexanol	
0	9	Critical P for 1-hexanol	
0	10	Critical V for 1-hexanol	
0	11	Melting T for pentanoic acid	
0	12	T de ebullición de pentanoic acid	
0	13	T crítica de pentanoic acid	
0	14	P crítica de pentanoic acid	
0	15	V crítico de pentanoic acid	

d)

Datos (Joback)	Δ Tf	Δ Tb	Δ Tc	Δ pc	Δ vc
Nonring increments:					
-CH3	-5.10	23.58	0.0141	-0.0012	65
>CH2	11.27	22.88	0.0189	0.0000	56
>CH-	12.64	21.74	0.0164	0.0020	41
>C<	46.43	18.25	0.0067	0.0043	27
=CH2	-4.32	18.18	0.0113	-0.0028	56
=CH-	8.73	24.96	0.0129	-0.0006	46
=C<	11.14	24.14	0.0117	0.0011	38
=C=	17.78	26.15	0.0026	0.0028	36
Oxygen increments:					
-OH	44.45	92.88	0.0741	0.0112	28
-O-	22.23	22.42	0.0168	0.0015	18
>C=O	61.20	76.75	0.0380	0.0031	62
O=CH-	36.90	72.24	0.0379	0.0030	82
-COOH	155.50	169.09	0.0791	0.0077	89
-COO-	53.60	81.10	0.0481	0.0005	82

Figure 1: Example of the proposed problems involving the estimation of thermodynamic properties.

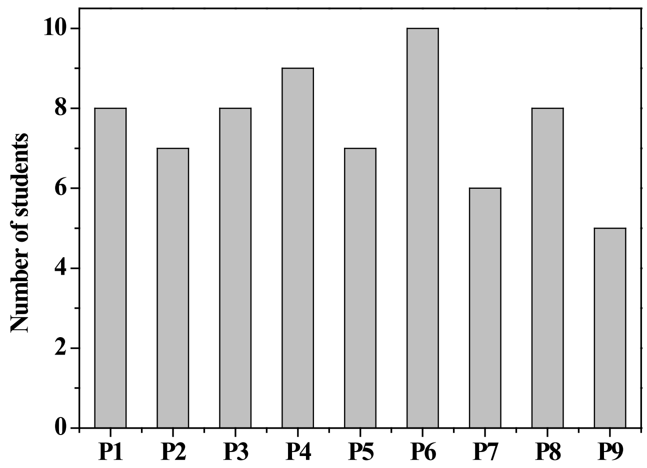

Figure 2: Number of students participating in each PBL/e-learning activity.

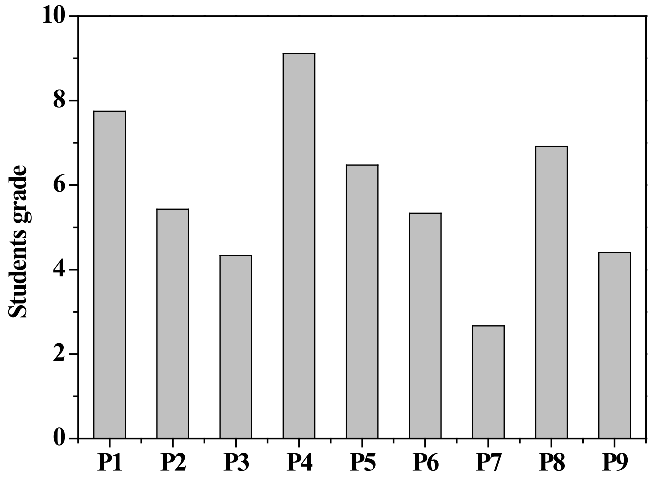

Figure 3: Average student grade for each PBL/e-learning activity.

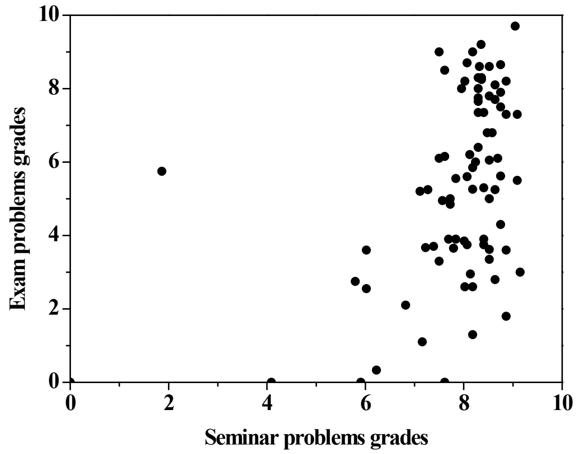

Figure 4: Comparison of grades obtained in individual exam problems versus working groups' seminar problems.

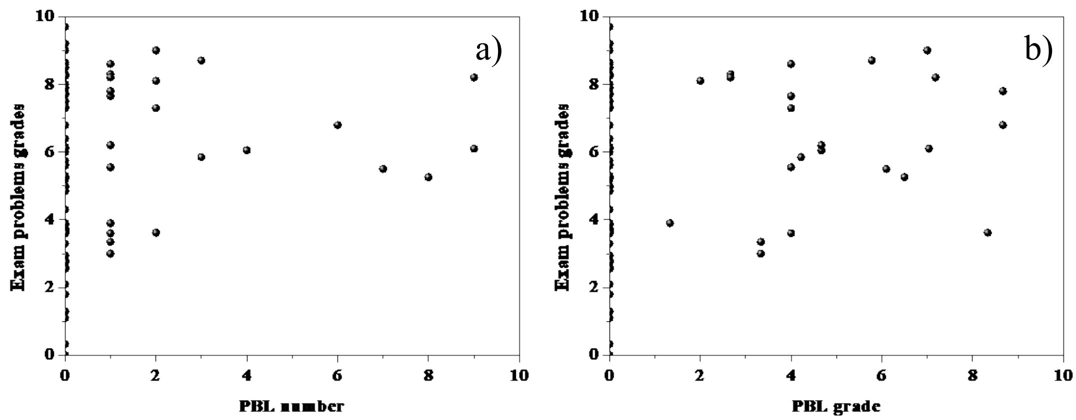

Figure 5: Comparison of grades obtained in exam problems versus PBL activities: a) versus number of PBL, and b) versus grade of PBL.

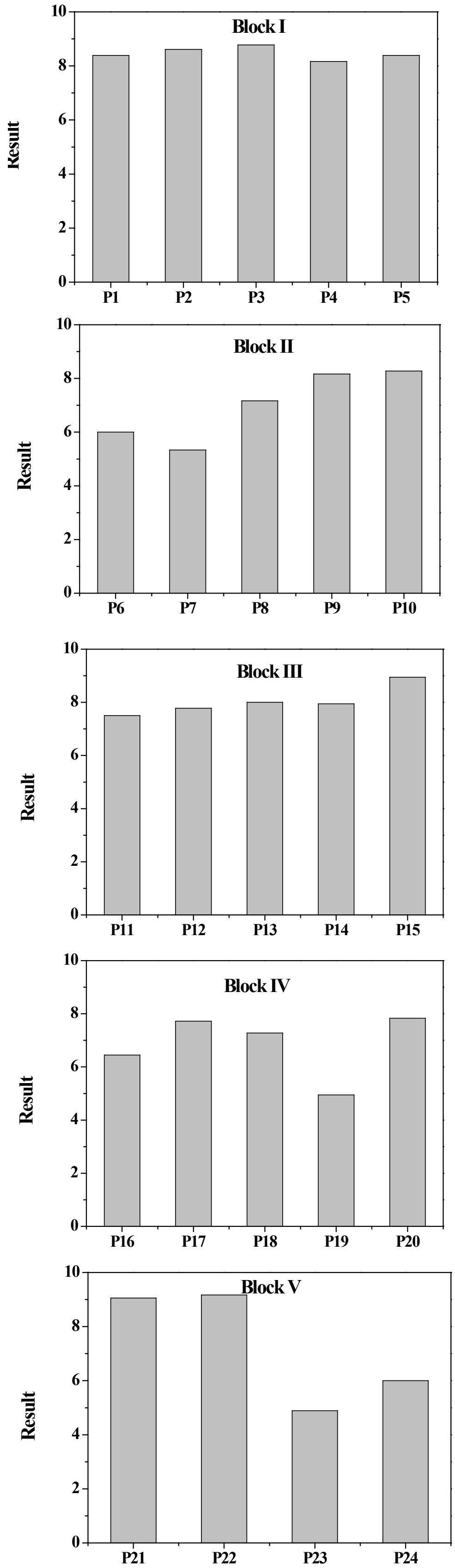

Figure 6: Results obtained for each question of opinion survey.

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