A picosat design course with synchronous internet teaching

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Abstract — *This paper reports on a pico -satellite design course o ffered to universities in Taiwan via internet synchronous teaching. The scope of this course is to provide students fundamentals and practice of system engineering, which can be applied immediately to the pico -satellite design projects. Under the support of Ministry of Education, this course organized a team of university professors and industry experts to give lectures and guide students to design pico-satellites. The students registered in this course were required to form in teams to deliver design repo rts at the end of each semester. This course was conducted with lectures given weekly. During the lecture hours, students were required to make presentations to update their progress on design projects. By the end of each semester, a contest on the design reports was held with all the students and lectures gathering at a place. In addition, a website of this course was set up available to students, that they could download lecture materials and homework assignment, as well as post questions and opinions co ncerning this course. In general, the lecturers were satisfied with the performance of students on their design reports, on the other hand a weakness was identified among students with regard to the training of system engineering and team work. A question naire survey was conducted in the past two years. I nformation obtained from the survey data concerning students ' efforts and opinions on this course is presented and discussed in this paper.*

Index Terms — *internet synchronous teaching, project -based learn ing, satellite system engineering*

INTRODUCTION

Due to the globalization of economy and the impact of new technologies to human life, many educators realize the urgency of engineering education reform to respond to the current and future needs of the society [1]. Grimson [2] addressed the need of re-engineering the curriculum for the 21st century, in which he pointed out that the changes require new approaches with the curriculum and by promoting active learning and encouraging students to be more creative. Responding to these calls for curriculum reform, project-based learning is known as one of the effective means for engineering students to gain the problem-solving ability [3]. Through learning by doing, students not only can synthesize and apply the knowledge learned, but also can exercise their creativity and team effort under the constraints given. In the literature, one can refer to a number of reports for the experiences of the courses with emphasis on project-based learning [4-6].

This paper reports on the recent development of a picosat design course via internet synchronous teaching. Realizing the emerging need of system engineering education in the country, three years ago the present authors formed a team to initiate a course entitled "picosat system engineering and design". In viewing that this multi-disciplinary course requires a wide range of expertise, this course was decided to be taught via internet. With this approach, this course was able to invite experts outside campus to give lectures on a part-time basis.

The scope of this course is to provide students fundamentals and practice of system engineering and guide students to go through the process of designing a satellite. In designing the pico-satellites, the students are required to form in teams. Therefore, through the design work, these students can also experience how to carry out a design project with team effort. This course is mainly for engineering students at the third-year undergraduate level and above, with assuming that students do not have any background in space engineering. Since this course is offered in two semesters, the course contents were formulated in such a way that in the first semester lectures are emphasized on the fundamentals of space engineering, and in the second semester lectures place emphasis on the technical aspects of the system and subsystems of a satellite, in order to help students to carry out the design work. By the end of each semester, a contest is held to evaluate the performance of the students based on their presentations and design reports on pico-satellites. The contest is held with all the students and the evaluators gathering at a place. Hence, the contest also provides a good opportunity for participants to exchange their ideas and opinions.

In the past two years, a questionnaire-based survey was conducted to collect the opinions and comments of students

on this course. In this paper, the information reduced from the survey data will be presented and discussed, which provides a valuable reference for future improvement on this course.

WHY GO FOR A PICOSAT DESIGN COURSE

Pico-satellite is referred to a satellite whose mass is on the order of 1kg. Encouraged by a recent proposal on promoting cubesat design projects for space engineering education [7] and the successful launching and operation of university pico-satellites [8-9] and nano-satellite [10] in 2003, pico-satellite projects become popular in quite a number of universities worldwide. This trend can also be realized from the 1st Annual Cubesat Developers' Workshop held at California State Polytechnic University, April, 2004 [11]. In the workshop, most of the participants came from universities. They gave presentations on their cubesat projects and performed fit check on their satellites, a step before integration test for launching.

The reasons for pico-satellites being favorably chosen by universities for space engineering education can be summarized in the following. A pico-satellite project is featured with the characteristics: (a) short turn-around time, which normally take one to two years effort from design to integration test, (b) low cost, which is affordable to university budget, (c) less complicated in technical requirements, which are apt to be handled by students, and (d) interdisciplinary in nature, which encourage students to learn more about the related topics in aerospace engineering, electrical engineering and mechanical engineering. Moreover, although a pico-satellite is small and less complicated, compared to a commercial satellite, it represents a highly integrated system working in space environment. Hence, the considerations in system integration definitely are challenging and demanding.

In developing this course, the first issue discussed was concerned with the main purpose of this course. A consensus was reached among the present authors that the major goal of this course is to educate students to have a good grasp on system engineering via designing a pico-satellite. Also, hopefully, the effort of this course would encourage universities to further manufacture pico-satellites for launching, which would benefit the space education in Taiwan greatly. Following this guideline, the approach adopted in this course was to start with a series of lectures on fundamentals and practical aspects of system engineering relevant to satellite design, followed by the technical considerations on the design of satellite system and subsystems.

ORGANIZING THE COURSE

The development of this course was started with organizing a committee, whose members actually include the authors of the present paper. Since the committee members work in different organizations, the meetings were usually conducted via internet for video conferencing. It should be mentioned that this course is supported by Ministry of Education, under the Aerospace Engineering Education Reform Program. One of the missions carried by this program is to enhance the quality of aerospace engineering education by promoting the collaboration between university and industry [12]. Thus, the committee represents a team of experts from the academia and the industry on the task of promoting space engineering education. The committee is coordinated under the effort of the program office, based at the Aerospace Science and Technology Research Center, National Cheng Kung University.

Extensive discussion on the scope of the course was made during the initial phase of course development. In considering that this course will be offered to undergraduate students mainly, the scope was laid out as follows: (a) to provide students knowledge of space system engineering, through the introduction of mission requirements and space environment, and the specifications of satellite system and subsystems, and (b) to provide students skills necessary to perform the conceptual design of a satellite.

Table 1 lists the topics of the course contents in the academic year of 2002. In the first semester, lectures were started with the introduction of satellite system engineering and mission requirements, then the implementation of these requirements into the design of system and subsystems of a satellite. In the second semester, more details on the design aspects of each of the subsystems were introduced, in order to help students to have a good grasp on their design work. It should be mentioned that the lecturers for the topics shown in Table 1 were invited from different organizations, some of which were from National Space Program Office, who are experienced in satellite design, and the rest were the professors from universities. Thus, coordinating the lecturers and integrating the lecture materials took some efforts initially. In fact, the coordination was made in committee meetings, and through e-mail communication. Usually e-mail was preferred, since it worked effectively without the need of video conferencing.

A remark on a lecture of Yamsat System Design arranged at the beginning of the second semester is made here. This lecture was suggested earlier in a committee meeting. The reason for this was that from the design reports delivered at the end of the first semester the evaluators noted that most of the students did not have a good understanding on system engineering with respect to satellite design. Hence, a suggestion made was to include a lecture on the design of Yamsat in the second semester, where Yamsat is a pico-satellite of 1 kg in mass completed earlier in National Space Program Office [13]. The purpose of this lecture was to provide students a practical example of pico-satellite design. Also, students could refer to the data of Yamsat for their design work.

Course lectures were given every Thursday in the evening, 6-8:30pm, via internet. Figure 1 shows a diagram

depicting the network of all the institutions involved in this course. Specifically, National Center of High-performance Computing served as a hub to communicate with all the institutions participating in this course, meanwhile monitored the internet quality. National Space Program Office offered the lecturers who are experienced in satellite design. At each participating universities, there were student teams and a supervisor who was responsible for monitoring student performance and provided guidance for course work and design projects. Further, at each of the institutions, a technical person specialized in internet networking was needed, who could provide timely assistance to resolve the internet problems during lectures. The internet employed for this course was TANet 1, which has 6 GBytes bandwidth and links all the university campuses in Taiwan. A Polycom system was equipped at each of the end-users, which provided real-time images and two-way voice communication.

In addition to the lectures offered via internet, the lecture materials and homework assignments were posted on a website designated for this course, which allowed students to download the lecture materials at their own convenience. On this website, a contact e-mail address was provided for Q and A. Students frequently used this e-mail address for asking questions concerning their design projects. These questions were answered in later lecture hours, or on the website.

Students were required to deliver design reports on the team basis by the end of each semester. Basically, a report given by the end of the first semester should provide a feasibility analysis on the idea proposed, including statements on the mission requirements and a balance analysis on the power and mass budgets; the report given by the end of the second semester should provide design data concerning the system and subsystems, to fulfill the mission defined.

To comply with the administration regulation of each university and to be of easy access for the students, this course was suggested to be offered as a regular course with 3-hour credits each semester in a two-semester academic year. The course credits will be awarded to each registered student by his or her university and the grade of the student will be given by his supervisor. To closely monitor the progress of the course, the supervisors also serve as the committee members of this course. Therefore, any problem in conjunction with the course can be timely brought up and discussed in the committee meeting.

STUDENT PERFORMANCE EVALUATION AND COURSE DEVELOPMENT

The evaluation of student performance maily was made through a contest held at the end of each semester. Evaluators served in the contest were invited from the lecturers of the course and supervisors of student teams. The contest included the items on oral presentations and posters of the satellite design projects, and the assignments of communication circuitry design, which were given earlier in the lectures. The winners of awards were announced immediately after the contest. Meanwhile, the evaluators would make comments to students concerning their performance.

A course review meeting was also held among the evaluators during the contest, and was proven very useful for later improvement on the course. Usually, the discussion would be carried on in later committee meetings, and led to some actions taken to modify the teaching methods and course contents. In the following, a summary of comments on student performance is given.

In general, the evaluators were satisfied with student performance based on their design reports. Particularly, the evaluators were impressed by the progress revealed from comparing the design reports of the first and second semesters. On the other hand, some concerns shared by all the evaluators are given below.

First of all, most of students did not think carefully how to integrate the subsystems into a satellite system. Secondly, students were inexperienced in team work. It was commonly seen that a student tended to focus on his own subsystem, while not paying too much attention to the interface with other subsystems. Moreover, frequently students did not realize that the mission chosen was too complicated to be managed. The physical constraints of a satellite and the space environment were not carefully considered.

Having realized the problems above, the evaluators strongly suggested in the course contents that more emphasis be placed on the system-level aspects of satellite design. Also, in the lectures every week, half an hour time was allocated for students to make presentations and questions. This stimulated students to give more careful thoughts about their design work.

In the first semesters of 2002 and 2003 academic years, there were 45 and 44 students, respectively, registered in this course, while in the second semesters of 2002 and 2003 the numbers of students were reduced to 35 and 22, respectively. In fact, among the 35 students registered in the second semester of 2002, 13 students were new in the course. Therefore, in either of the academic years, the drop rate with regard to the students registered in the first semester is about 50%.

Normally, a student team consisted of 6 students or more. Due to the problem of students dropping the course in the second semester mentioned above, most of student teams had to be re-organized at the beginning of the second semester. Nevertheless, referring to the student performance evaluation in the second semester, this re-organization did not seem to cause any adverse effect. Also, referring to the question 9 in category I given in the next section and the survey data obtained in Table 3, it shows an encouraging indication to the course committee that more than half of the students were participating fully to the design work, regardless of many straining efforts they had to endure for the course.

ANALYSIS RESULTS OF THE SURVEY DATA

In the past two years, a questionnaire survey was conducted to collect comments and opinions of students on this course. The questionnaire consists of questions in three categories, which are given below for reference.

I. Questions to a student concerning his/her effort on this course:

1. Did you attend the internet lectures every week?
2. How often did you visit the website of this course?
3. How often did you visit other websites for the information relevant to this course?
4. How often did your team have meeting for the design project?
5. Did you attend the team meeting every time?
6. How much time did you spend on this course every week, excluding the class hours?
7. How many subsystems did you participate in your satellite design project?
8. As a team member, do you think your design workload is reasonable?
9. How many team members are actively participating in the design project?

II. Questions to a student for his/her comments on this course:

1. Could you name any other courses in your department, whose contents are overlapped with the present one?
2. Did you experience any learning difficulty with the present internet teaching?
3. Provide your comments on (a) the quality of the internet during lectures; (b) the lecture materials of this course; and (c) internet teaching, based on what you learned from this course, versus traditional teaching in classroom.
4. Please weigh the contributions of the following factors, in terms of percentage, to your design work: (a) lecture materials; (b) guidance of supervisor; (c) independent study; (d) discussion with team members; (e) others.
5. Did you learn something new and interesting from this course? And, would you like to pursue further study along this direction?

III. Questions to a student for general comments

1. Will you recommend this course to other students?
2. Make your comments on the answer given in the previous question.

This questionnaire survey was conducted in the second semester of the 2002 academic year, and at the ends of the first and second semesters of the 2003 academic year. The information obtained from the survey data can be described below.

I. Concerning the questions of the category I:

1. More than 50% of students said that they attended all the lectures, while almost all the rest students said that they missed the lectures no more than 3 times a semester.
2. About 20-30% of students visited the website of this course at least once a week, and about 50% of students visited the website once every two weeks.
3. About 40% of students visited other websites at least once a week for the information relevant to this course, while about 40-50% of students visited websites once every two weeks.
4. More than 60% of students said that they have team meeting held every week.
5. More than 80% of students attended all the weekly meetings, and the rest students attended at least 50% of the weekly meetings.
6. Table 2 shows the survey result concerning the number of hours spent weekly on this course. The statistics indicate the percentages of students in different ranges of hours. As noted, students in the first semester of 2003 tended to spend less time on this course than the students in the second semester of 2003 did. Also noted, the students of 2002 spent more time on this course than the students of 2003 did.
7. About 80% of students were involved in one subsystem design work, while the rest 20% were involved in two to three subsystems.
8. About 60% of students said that their workloads in the design projects were reasonable, but the rest expressed either fair or not reasonable.
9. Referring to Table 3, students in the second semester of 2002 showed more active participation in design projects, compared to the students of 2003. This deserves a further study why the students of 2003 did not perform so well as the students of 2002 did.

II. Concerning the questions of the category II:

1. About 50% of students indicated that the overlap between the present course contents and other course contents offered in their universities is no more than 20%, while about 30% of students indicated that the overlap is more than 50%. Since the students registered in this course were from different universities, the statistics simply

reflect that some of the universities offer other courses in space engineering, while the rest are not. But, it is known that none of these courses include hands-on design of a satellite system.

2. Referring to Table 4, more than 80% of students admitted that they experienced learning difficulty with the present internet teaching, compared to traditional teaching in class. In the second semester of 2002 and the first semester of 2003, a significant percentage of students indicated that the learning difficulty was rather serious, referring to the first two categories in the table. But, in the second semester of 2003, the percentage of students in these two categories was greatly reduced.
3. Referring to Table 5, about 50% of students were not satisfied with the quality of the internet. Also, the statistics show that this problem has not been improved in the past two years. The problem was mainly due to that TANet 1 is a campus internet system, whose data flow rate is beyond control. Despite of a large amount of efforts made in this course, including improvement on the bandwidth of campus network and technical assistance during the lectures, unexpected problems could be happened. Such problems were also addressed by Stephens *et al.* [14] in developing an internet teaching course for multi-universities. Actually, this poses a common issue of synchronous teaching using public internet, which deserves further study in the future.
4. Referring to Table 6, it is shown that about 20% of students favored the lecture materials presented in the Powerpoint format to the traditional lecture materials, while about 60% of students commented that the Powerpoint lecture notes were acceptable, nevertheless improvement was desirable, and 20% of students felt that the lecture materials needed immediate improvement. The remarks made by the latter students are that the Powerpoint files provided the outline of the topics only, whereas they had difficulty to get further information about the topics taught.
5. Referring to Table 7, it is seen that most of the students commented that the lecturing techniques employed in the present course were acceptable, nevertheless improvement is desirable. The remarks relevant to this issue include (a) the video images of internet teaching were not attractive to students, (b) the lecturers did not give detailed explanation on the design tools, for instance, the design software, and (c) students were not able to contact the lecturers in time to get help on design projects.
6. Table 8 shows the distribution concerning the contributions of the five factors indicated to design projects. The percentage values shown represent the mean values reduced from the survey data. It is interesting to note that the percentage values on the factor "guidance by supervisor" are decreased significantly from 2002 to 2003, while the percentage values on the factor "independent study" are increased from 2002 to 2003. The variations seem to imply that the students of 2003 were better at handling the design work by themselves, while the students of 2002 who had no previous knowledge of this course relied more on supervisors' guidance. On the other hand, referring to Table 3, the variations mentioned above might have a negative implication that the students of 2003 tended to do the design work more independently, while not paying too much attention to team effort.
7. Referring to Table 9, it shows that by the end of the first semester of 2003 about 59% of students show no strong interests to continue this course. Actually, the students who continued this course in the second semester were 50% of the total students. On the other hand, the percentage of the students in the second semester who showed no strong interests was 14%, equivalent to 7% of the students of the first semester. These statistics reveal an interesting finding that most of students did not change their opinions regarding this question in the second semester.

III. Concerning the questions of the category III:

1. Referring to Table 10, about 40% of students expressed that they will positively recommend this course to other students, while 40-50% said that they will consider to recommend, and the rest expressed that they will not consider to recommend.
2. The remarks made by the students who will positively make recommendation are summarized below. The experiences gained from this course on interdisciplinary training, system engineering, team work, and hands-on design of a satellite were rewarding, which could not be obtained from other courses offered in his/her department.
3. The remarks made by the students who expressed that they will consider to make recommendation are summarized below. This course is challenging, which take significant amount of efforts and time, nevertheless it is worthwhile. On the other hand, it is a concern that students were not able to get help from experienced person to resolve the problems encountered in the design work. Hopefully, this situation could be improved in the future.
4. The remarks made by the students who expressed that they will not make recommendation are summarized below. The satellite design project appeared too difficult to be handled. The lecture materials of the present internet teaching were too abstract. It was difficult to find experienced person helping to resolve the problems encountered in the design work.

DISCUSSION

The remarks made by students on the questions in Category III deserve further discussion here. First of all, it seems a

good understanding among all the students that the design project in this course is challenging and requires a fair amount of efforts to accomplish. Favorable and unfavorable remarks seen in this respect were merely different opinions held by students.

Concerning the unfavorable remarks on the course contents and the design project, further comments can be made below. Speaking of the course contents, it is an issue of balancing between breadth and depth, which generated a lot of discussion in the previous committee meetings. The contents of this course will be tailored further with the considerations of student background and the technical information required for satellite design. Also, it is desirable that lecturers could prepare lecture notes in detail or even write a textbook for this course in the future.

Concerning the design project, a remark made by many students was that they were not able to obtain advices in time for their design work. This was recognized as an inherent problem with internet teaching. Some attempts were made in this course to remedy this problem. In the second semester of 2003, each lecturer gave homework assignments on the website two weeks in advance, so that student teams could prepare presentation and questions during lecture hours. The results of this change were encouraging. By the end of the semester, most of the students expressed that they were in favor of this arrangement, although they admitted that preparing presentation every week gave them extra pressure. Further considerations along this direction to enhance the interaction between lectures and students will be made in the future.

CONCLUDING REMARKS

Development of this course represents a team effort of collaboration between industry and university. This course also represents a successful example of utilizing modern internet technology to offer lectures at dispersed locations in a real-time manner. In summary, two features of this course are especially worthwhile mentioning below. Firstly, the course contents covered a wide range of topics relevant to the design of a pico-satellite. This was made possible by inviting experts from different organizations to give lectures. Meanwhile, students were able to conduct satellite design under the guidance of these experts. Without their help, these results could hardly be achieved by a single instructor in a university. Secondly, this course was organized and coordinated through an inter-university program supported by Ministry of Education. Assisted by the program, the resources of academic institutions and industry were well coordinated, which could hardly be achieved in a traditional course.

Concerning the performance of students in this course, the lecturers were satisfied by their design reports, on the other hand it was noted that students needed more training in system engineering and team work.

Fruitful information was obtained from the statistical analysis of the survey data. The statistics show that most of the students attended the lectures weekly, and actively participated in design projects. Compared to the traditional class teaching, most of the students experienced learning difficulty at different levels with the present internet teaching, and suggested that improvements on the internet quality and the lecture materials be desirable. In addition, students made comments on the course contents and the method of internet teaching. In reference to these comments, actions will be taken in the future to improve this course.

The statistics show that about 50% of the students registered in the first semester continued to take the course in the second semester. Moreover, the survey data indicate that about 40% of the students registered in the first semester showed strong interests to pursue future study in this direction. Coincidentally, about the same amount of students expressed positively that they will recommend this course to other students. Therefore, based on the survey data, one can say that about 40% of students registered in this course learned quite well and showed strong interests in space engineering.

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TABLES AND FIGURES

TABLE 1
Outline of the course contents in the academic year 2002.

Course outline of the first semester	Weeks
System Engineering Process and Requirements	1
Spacecraft Mission Design	2
Space Powers	1
Communication	1
Configuration and Structural Design	1
Mid-term reports	2
Attitude Determination and Control	1
Thermal Control	1
Mid-term written exam	1
Flight Software	1
Launch Vehicle	1
Final report	1

Course outline of the second semester	Weeks
Spacecraft System Design	1
YamSat System Design	1
Mechanical Design	1
Electrical Power	1
Thermal Control	1
Telemetry, Tracking, and Command	1
Command & Data Handling	1
Attitude Control & Determination	1
Mid-Term Exam	1
Structure & Mechanism	1
Thermal Control	1
Electrical Power	1
Telemetry, Tracking, and Command	1
Command & Data Handling	1
Attitude Control & Determination	1
Flight Software	1
Final Report	1

TABLE 2
Statistical distributions of students' opinions concerning the time spent on this course weekly, excluding the class hours.

Hours per week	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Over 6	20%	2%	9%
3-6	48%	23%	43%
1-3	29%	68%	48%
Less than 1	3%	7%	--

TABLE 3
Statistical distribution of individual student comments on the participation of team members in his/her design project.

Participation of team members, in terms of percentage	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
100%	74%	54%	68%
80%	26%	24%	5%
60%	--	20%	18%
40% or less	--	2%	9%

TABLE 4
Statistical distributions of students' comments concerning learning difficulty experienced with the present internet teaching

Comments	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Totally impossible to learn things like in traditional classroom	3%	4%	5%
Not entirely	29%	50%	14%
Some difficulty, but not serious	57%	33%	81%
No problem at all	11%	13%	--

TABLE 5
Statistical distributions of students' comments concerning the internet quality.

Comments	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
It is not good, and needs immediate improvement	9%	13%	3%
It is not so good, and immediate improvement is desirable	9%	33%	53%
Acceptable, but improvement is desirable	82%	46%	38%
Good, the result of learning can be even better than that in traditional classroom	--	8%	6%

TABLE 6
Statistical distributions of students' comments concerning the contents of lecture materials.

Comments	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Not good, and needs immediate improvement	--	2%	10%
Not so good, and immediate improvement is desirable	9%	7%	10%
Acceptable, nevertheless improvement is desirable	71%	73%	60%
Good, the result of learning can be even better than that in traditional classroom	20%	18%	20%

TABLE 7
Statistical distributions of students' comments concerning the present internet teaching versus classroom teaching.

Comments	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Not good, and needs immediate improvement	--	--	--
Not so good, and immediate improvement is desirable	9%	4%	9%
Acceptable, nevertheless improvement is desirable	82%	49%	77%
Good, the result of learning can be even better than that in traditional classroom	9%	47%	14%

TABLE 8
Statistical distributions of individual student opinions on the contribution of the five factors indicated to his/her design project.

Factors	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Lecture materials	20.4%	26.4%	22.9%
guidance of supervisor	24.4%	13.1%	19.3%
independent study	27.5%	36.5%	34.3%
discussion with team members	21.5%	19.9%	20.9%
Others	2.9%	4.2%	2.5%

TABLE 9
Survey results concerning a question: Did you learn something new from this course? And, would you like to pursue further study in space engineering?

Answers	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Positively yes	63%	41%	86%
Yes, but no strong interests in pursuing further study in this area	30%	48%	14%
No	7%	11%	--

TABLE 10
Survey results concerning a question: Will you recommend this course to other students?

Answers	2nd semester of 2002	1st semester of 2003	2nd semester of 2003
Yes, definitely	46%	36%	43%
Possibly yes, I will consider to recommend to other students	36%	44%	52%
No	18%	20%	5%

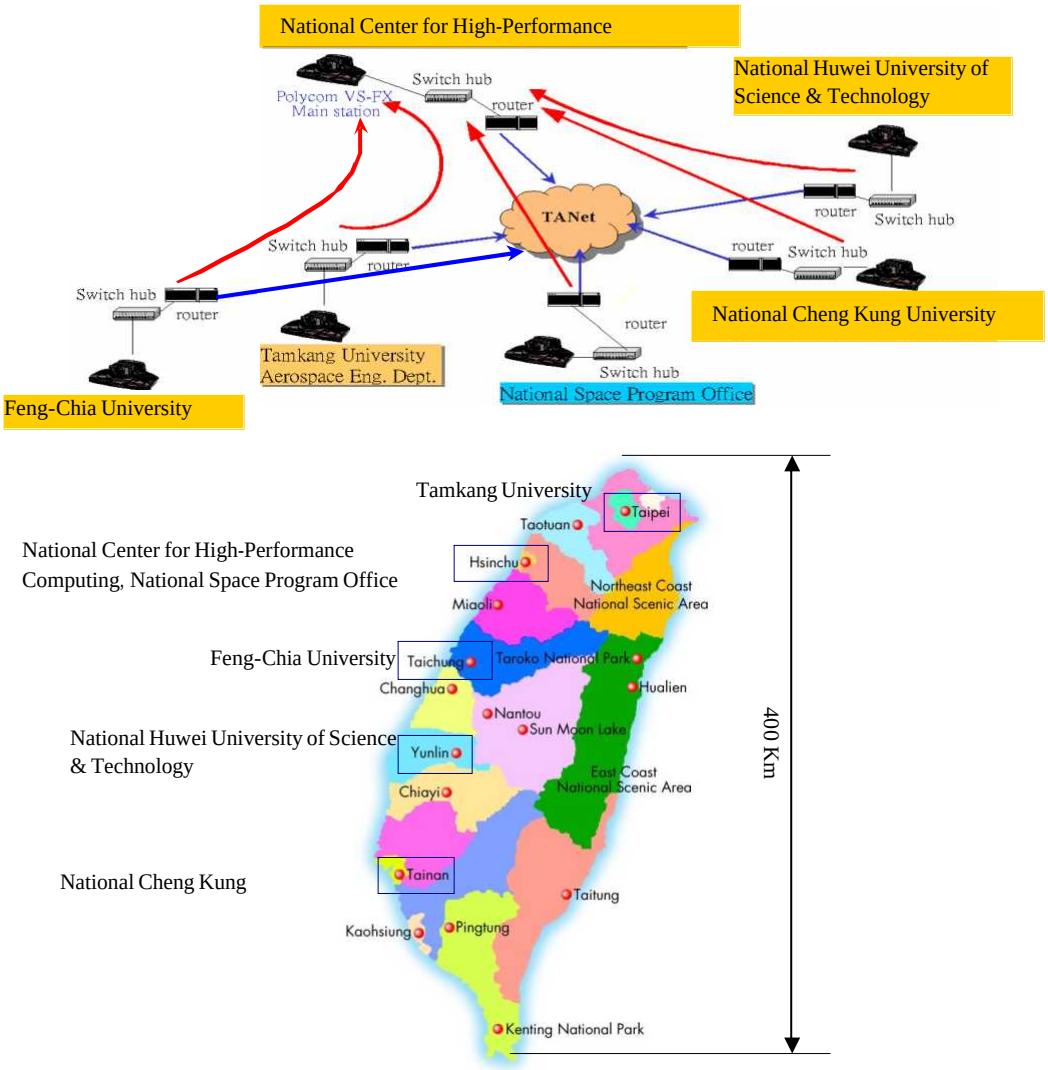

FIGURE 1
Internet networking in the present course