AC 2007-2221: DESIGNING A PROJECT-BASED CONSTRUCTION ENGINEERING COURSE

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Designing a Project-Based Construction Engineering Course

Abstract

The traditional approach to the design and delivery of an engineering course is the delivery of a series of lectures, which are supplemented by the solution of manageable, small problems at the end of chapter of the book used in the course. These lectures are based on discipline-specific or general theory of the subject matter in question. Students are expected to understand (and sometimes memorize) the underlying theories with the hope that they will be able to apply them in their future professional careers. In this case, students are limited to the solution of small problems, most of which are not representative of real-world problems. It can asserted that, prior to the genesis and adoption of ABET EC 2000 accreditation criteria, engineering programs are not required to teach team and real world problem-solving skills to their graduates. Wulf and Fisher acknowledged that "many of the students who make it to graduation enter the real workforce ill-equipped for the complex interactions, across many disciplines of real-world engineered systems". Engineering projects and systems encompass a broad spectrum of issues ranging from technical details, politics, economics, societal effects, environmental impacts, time/cost constraints, regulatory requirements to corporate entities and management styles. Understanding and effectively dealing with the complex interactions of these factors will define the success or failure of the project. However these important skills are learnt on the job through trial and error. Sometimes the results are unfortunate. This work involves the incorporation of a real-world project (a Commercial Building Project) into the design and delivery of a Construction Engineering course. Students are taught a limited quantity of theory. Most of the theory is to refresh their memories of what they have already learnt in other classes. The theory is meant to jog their thinking and make them relate what they have learnt to the problem they are trying to solve in a real world setting. However a greater emphasis is placed on applying what they have learnt in the classroom to solve various aspects of this complicated building project in a multidiscipline environment. The entire project is broken down into bit-size projects that can be completed in a week or two. Each sub-project is used to address a particular aspect of the construction management process. The initial project involves the submission of resumes and the formation of teams based on the expectations/experience of the students in the class. The course design, delivery and assessment are driven by ABET EC 2000 – Criteria 3(a)- (k). The course objectives will be assessed at the end of the course and remedial actions will be devised to address any shortcomings.

Introduction

In an era of changing market forces and increasingly complex projects/designs/systems, engineering students are expected to be introduced to real world problems as part of their training. Engineering students must be exposed to the complex interactions, across many disciplines, of real-world engineered systems. Teaching engineering and engineering-related courses to undergraduates is an interesting and rewarding task. Graduates from engineering programs must not only be technologically capable, but they are also expected to exhibit real-world problem solving skills, be team oriented, be able to function in a multi-disciplinary environment. Construction graduates must possess technical strength coupled with communication (written and speech), and soft skills. In most of the capstone courses, students are given a real-world problem to solve over a period of a semester or a year. Many programs have capstone / project-based courses, which are aimed at training students in solving real world problems. Some programs have courses which run for a year. Walker and Slotterbeck[1], in studying the incorporation of teamwork into software engineering curriculum, concluded that: (i) there is not enough time to teach software engineering skills and also carry out a significant team-based project in a single term, (ii) the software development process is best learnt by developing software under real-world conditions and (iii) team skills and effective communication are crucial to software engineering curriculum.

Walker and Slotterbeck in analyzing several capstone courses in Software Engineering[1] , suggested that (1) the engineering concepts can not be fully taught to students in a single term, (2) the software development process is best learnt in a real-world environment and (3) teamwork and effective communication (written and presentation) are crucial to engineering programs.

Research Methodology

The methodology employed in this research involves review of the ABET accreditation process, particularly Criterion 3(a-k), followed by a discussion of the methodology generally employed to incorporate real world projects into engineering curricula (capstone project course). A new project-based course design and delivery will then be devised to incorporate real world projects into the engineering classroom.

ABET Accreditation and Criterion 3 (a-k). Program Outcomes and Assessment

The debut of engineering accreditation can be traced to the formation of the Engineers's Council for Professional Development (ECPD) in 1932 followed by the first accreditation visit to Stevens Institute of Technology and Columbia University in 1935[2]. ABET accreditation of engineering and technology programs is paramount to the future professional licensing of their graduates. Accreditation brings the requisite quality and elite status to engineering programs.

Criterion 3 (Program Outcomes and Assessment) is generally regarded as the mainstay of the ABET accreditation. As per ABET accreditation requirements in the context of EC 2000, engineering programs must demonstrate that their graduates possess the following skills:

"(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulates, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice." [2].

According to ABET, these outcomes are the minimum knowledge and skills sets that students who complete a course of study in an ABET-accredited engineering program should possess.

Approaches to Bringing Real World Projects into the Engineering Classroom

The options available to engineering programs to address real-world problems in their curricula are: (1) traditional capstone courses, (2) spreading the real-world project experience over a number of courses, (3) internship and (4) innovative incorporation of real-world projects into engineering courses.

The traditional capstone course approach involves assigning a real world project to students at the beginning of the course and expecting them to solve the problem using knowledge obtained in other parts of the curriculum or seek limited help from one faculty member or a faculty team. This is the most popular way of bringing real-world projects into the engineering classroom. It is therefore applied across engineering disciplines. The downside of this approach is that:

- students are likely to carry the same short-comings and deficiencies inherent in any curriculum into the capstone project and into the real world;
- there is very little feedback, if any, in capstone projects since students are rarely given adequate feedback on a continuous basis,
- there is no theoretical content attached to capstone courses, depriving students of the ability to relate the theoretical underpinnings of knowledge in the discipline to the solution of real world problems,
- students are not eased into the solution of real world problems but are rather given a shock therapy version of real-world problems. They may therefore find the problem overwhelming even though the process is rewarding.

Spreading the real-world project over several courses as some engineering programs do, has its own shortcomings too. Some of these are:

- the loss of the importance of time;
- the amount of coordination and synergy required in the curriculum to make it work may be nonexistent;
- possible loss of team members due to attrition and/or graduation
- students may not possess the requisite knowledge to solve some aspects of the project in the earlier part of their studies

The use of internships alone to expose students to real-world problems may have some inadequacies as well, namely:

- companies/employers assign students to repetitive or short term tasks to either reduce mistakes or ensure timely completion;
- the experiences of students in internships vary from company to company. There is no assurance that students will be exposed to what they are required to learn during internships;

- some students may not be lucky enough to have the right internship at the right time;

Course Design

Course design involves the planning and structuring of a specific course of study to attain the desired/requisite academic, institutional and program accreditation goals, in the context of a Bloom's taxonomy of educational objectives. Generally course planning/design is considered as the process of identifying the contents of a course and defining measurable objectives[3] . Particular attention must be paid to the design process since courses are normally tailored and required to serve a very specific purpose in the entire education process. The design process involves identification of requisite goals and objectives, course outcomes, development of satisfactory content, selection of method of instruction or a mechanism to achieve goals/ outcomes and assessment of student learning [Figure 1]. In the assessment process, it must be demonstrated that outcomes important to the mission of the organization, program objectives, accreditation (ABET) requirements, etc. have been measured and met.

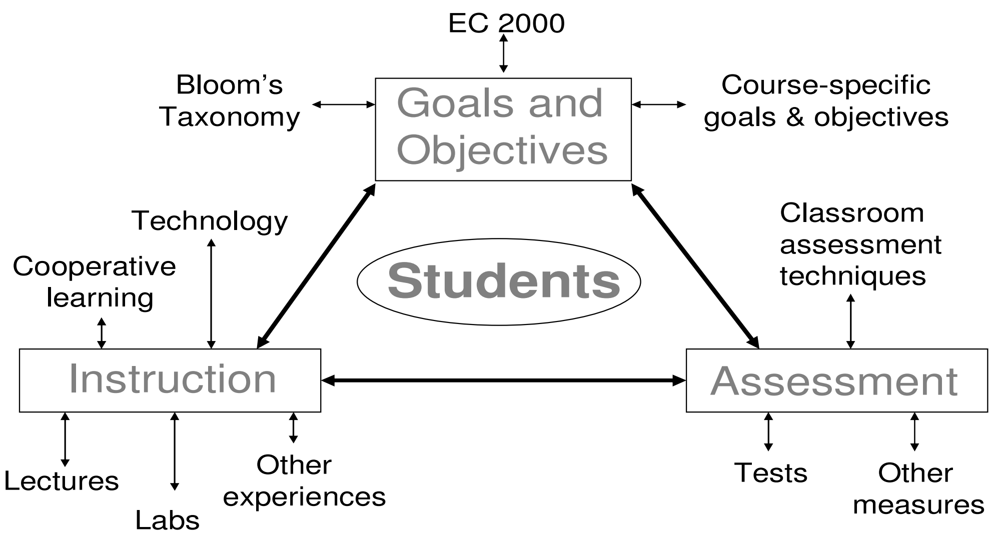

Figure 1: Approach to Course Design[3]

Under ABET EC 2000 continuous improvement requirements, program objectives and outcomes important to the institution and academic program must also be tracked. The design of CME 412 (Construction Management) is outlined below.

Course Description

The actual course is described in detail in the text below.

I. *Course Number and Name:* CME 412: Construction Management (3 Credits)

II. Catalog Description: Covers the concepts of development and organization of project, project contract administration, project delivery systems, management methods, management information systems, constructability review, value engineering and construction productivity. Prerequisite: CME 403 (Scheduling and Project Control).

III. *Textbook:* Edward R. Fisk and Wayne D. Reynolds, Construction Project Administration, 8th Edition, Pearson Prentice Hall, 2006

IV. *Course Objectives:* At the completion of this course, the student will:

1. have an understanding about how to administer a construction contract and how to properly utilize the required paperwork necessary for the successful completion of the project.
2. be familiar with the different types of project delivery systems available for building a project.
3. become skilled in the use of the project management software "Expedition".
4. understand the project specifications and how they are used to achieve a successful outcome to the project. They will also understand how the specifications work with the construction drawings.

V. *Project Management:* Students will manage a real-life project in groups of 4 or 5. Students are required to rotate roles at each stage of the project. Project documents will be made available in the Architecture Library for use by the project teams. The project documents are considered proprietary information and must not be disclosed to any second party without the proper authorization. Teams may have to share the documents. Documents can only be checked out overnight or during the weekends. This project management aspect of the course is an important educational/learning experience for you as a student and so give it all you can.

There were about 6 projects spread over the course of the semester. Three groups presented their project reports and faced intense questioning at the end of each project.

VI. Grading: The grade in this course will be based on in-class work, homework assignments and project work. Because class attendance and participation are integral parts of this course, attendance and class participation are expected at all sessions unless the student has made prior arrangements. Missed assignments may be made up only when permission has been granted before class. All assignments are due at the beginning of class on the date assigned.

Element	Points
Exams: (2 @ 50 points)	100
Assignments:	70
In-class	30
Activities/Quizzes:	300
Projects	
TOAL POINTS	500

The grades will be assigned as: ≥90% = A; ≥80%=B; ≥70%=C; ≥60%=D; Less than 60%=F

Date		Topic	Reading	Project
Jan	11	Introduction, Administrative Trivia	Ch.1	1-page Resume
	13	Project Delivery Systems	Ch 1	Site Visit/Resume
	16	**MLK Holiday**		
	18	Project Delivery Systems Continued	Ch 1	Project Prep
	20	Project Delivery Systems Continued	Ch 1	Project: Staging Plan
	23	Responsibility and Authority	Ch 2	Project
	25	Responsibility and Authority	Ch 2	Project
	27	Resident Project Rep – Office Responsibilities	Ch 3	Project
	30	Resident Project Rep – Office Responsibilities	Ch 3	Project
Feb	1	Documentation Records and Reports	Ch 4	Project
	3	Documentation Records and Reports	Ch 4	Project: Bid Opening
	6	Documentation Records and Reports	Ch 4	Project
	8	Electronic Project Administration	Ch 5	Project
	10	Specifications and Drawings	Ch 6	Project: Bid Tab
	13	Specifications and Drawings	Ch 6	Project
	15	Using Specifications – Contract Administration	Ch 7	Project
	17	Construction Laws and Labor Relations	Ch 8	Project
	20	**Presidents Day Holiday – No Classes**		
	22	Construction Safety	Ch 9	Project
	24	Meetings and Negotiations	Ch 10	Project: Schedule & Contracts
	27	Risk Allocation and Liability Sharing	Ch 11	Project
Mar	1	Preconstruction Operations	Ch 12	Project
	3	Preconstruction Operations	Ch 12	Project
	6	Planning for Construction	Ch 13	Project
	8	CPM Scheduling for Construction	Ch 14	Project
	10	**MIDTERM EXAM 1**		
	13	**Spring Break**		
	15	***Spring Break***		

	17	**Spring Break**		
	20	Construction Operations	Ch 15	Project
	22	Construction Operations	Ch 15	Project
	24	Value Engineering	Ch 16	Project
	27	Value Engineering	Ch 16	Project
	29	Measurement and Payment	Ch 17	Project
	31	Construction Materials & Workmanship	Ch 18	Project
Apr	3	Changes and Extra Work	Ch 19	Project
	5	Changes and Extra Work	Ch 19	
	7	Construction Meeting		Project
	10	Claims and Disputes	Ch 20	Project
	12	**MIDTERM EXAM 2**		
	14	**Holiday/Recess**		
	17	**Holiday/Recess**		
	19	Claims and Disputes	Ch 20	Project
	21	Claims and Disputes	Ch 20	Project
	24	Pre-final Inspection		Project
	26	Project Closeout	Ch 21	Project
	28	Project Closeout	Ch 21	Project
May	1			Project
	3			Project
	5			Project

ABET-Driven Evaluation and Assessment

The assessment tools that were employed to measure and track learning outcomes of the course objectives and ABET criterion 3 (a-k) are assignments and projects. Team membership skills, class presentations, and the professional nature of a team's work (as judged by faculty and project manager) were worked into the assessment of the projects. The project-based course design and delivery approach involves the following:

- employing 2 course instructors (Professor and Project Manager);
- using a High-Tech Building Project
- the project is divided into manageable sections
- students are introduced to each phase of the project
- provision of guidance during phased projects
- delivery of course notes in synchronization with projects and form theoretical basis of project solution.
- solutions are discussed in class after each phase
- better learning curve and shortened learning process.

The evaluation and assessment process in the context of ABET EC 2000 is shown in Figure 2 below.

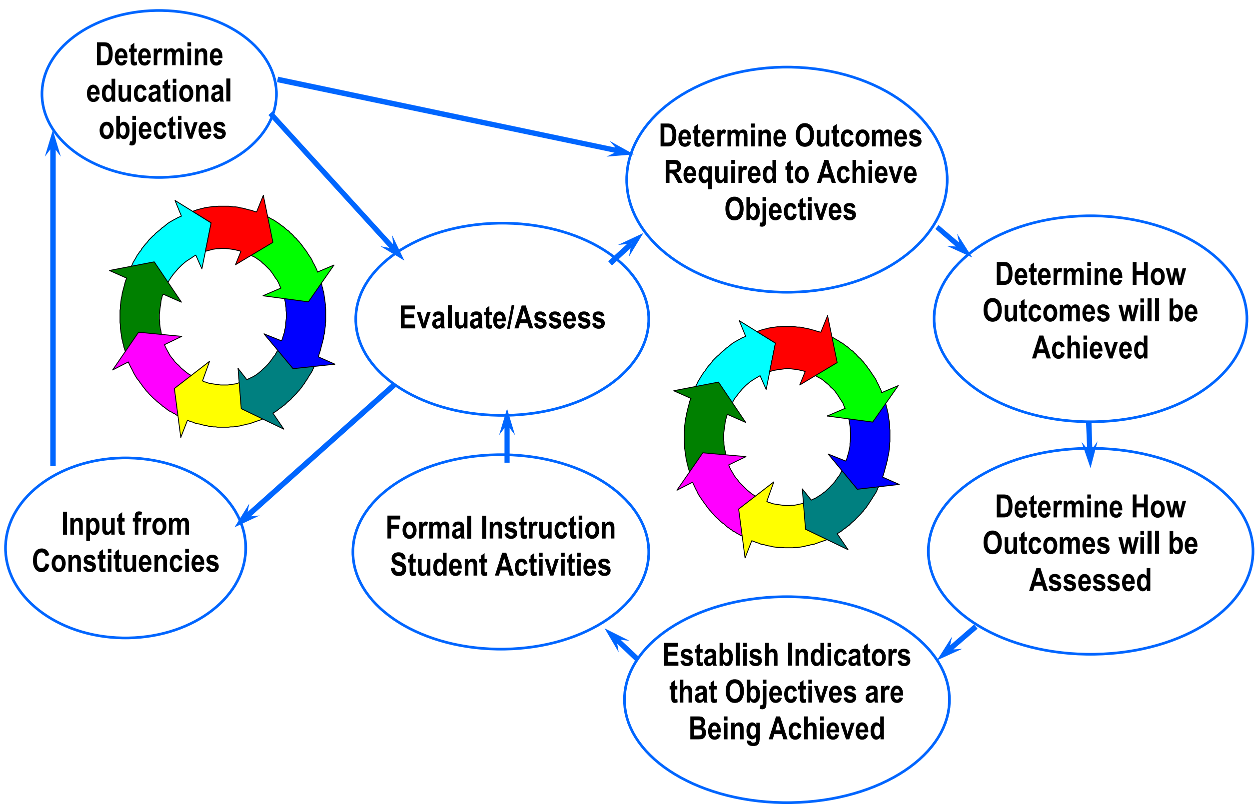

Figure 2: Evaluation and Assessment Loops[5]

Educational objectives are determined using inputs from the constituencies. The constituencies are ABET, industry, the University, etc. The entire process as depicted above is a continuous improvement process.

Course Data Analysis and Discussions

Data was collected and analyzed as part of the assessment of the effectiveness of this innovative course design and delivery system. Each of the course objectives was assessed using the SROI (Students Rating of Instruction), class projects and class assignments. Statistics (class mean) for each of the activities that directly relate to a particular course objective are summarized below.

1. Be able to explain how to administer a construction contract and how to properly utilize the required paperwork necessary for the successful completion of the project [g]

Assessment Technique Tool	Class Average
SROI(Students Rating of Instruction)	79
Project 3	89
Project 4	76

Project 5	81
Project 6	76
Assignment 1	79
Assignment 2	98
Assignment 3	97
Assignment 4	89
Assignment 5	100
Assignment 6	95
Assignment 7	98
Assignment 8	80

2. Be able to explain different types of project delivery systems available for a project [k]

Assessment Technique Tool	Class Average
SROI	83
Project 4	76
Project 5	81
Project 6	76
Assignment 1	79
Assignment 3	97
Assignment 4	89
Assignment 5	100
Assignment 7	98
Assignment 8	80

3. Become skilled in the use of the project management software "Expedition" [k]

Assessment Technique Tool	Class Average
SROI	70
Assignment 6	95
Assignment 7	98

4. Be able to explain project specifications and how they are used to achieve a successful outcome to the project. [h]

Assessment Technique Tool	Class Average
SROI	83
Quiz 2	65
Project 3	89
Project 4	76
Project 5	81
Project 6	76
Assignment 2	98
Assignment 3	97
Assignment 6	95

Assignment 7	98
Assignment 8	80

5. Be able to explain how the specifications work with the construction drawings [h]

Assessment Technique Tool	Class Average
SROI	84
Quiz 2	65
Project 3	89
Project 4	76
Project 5	81
Project 6	76
Assignment 2	98
Assignment 3	97
Assignment 7	98

For each ABET Program Learning Outcome, the average grade for the corresponding Course Objective is entered into the table. An Average Rating for each Program Learning Outcome is determined and entered into Table 1 below.

Program Learning Outcome Data						
Program Learning Outcome	Course Objectives with Overall Class Average					Average Rating
	1	2	3	4	5	
[g]	87					87
[h]				85	85	85
[k]		86	87			87

Table 1: Summary Statistics of ABET Program Learning Outcomes

The average rating of Program Learning Outcomes was between 85% to 87%. The variation in student performance may be attributed to a number of reasons, viz;

1. Time Constraints - the students were pursuing other courses in addition to this course. They had to read, analyze and synthesize a lot of information in the form of specifications, change orders, drawings, etc. in a limited amount of time. It was quite obvious that some of the students (especially the seniors who had accepted jobs as project engineers/managers) were oblivious to the challenges of the profession. Students have not been challenged enough prior to the introduction of this approach to course design and delivery.
2. Lack of Resources and Deficiencies - this course is very similar to a capstone course. However students were working by themselves, but were guided throughout the phased

projects. Students were expected to apply knowledge from other courses, especially Contracts and Specifications. Most of them had not seen or worked on an actual contract document before. This lead to some frustration. The lowest average project score of 76% occurred during Project 4. Project 4 was entirely on contracts. Two of the teams had low scores of 35% and 36%.

3. Group Dynamics – some of the students were complaining about the performance of other group members. I had meetings with these students and their colleagues later on informed me that the issues had been resolved.
4. Involvement in Capstone – this course was run concurrently with the actual capstone course and some of the students were not too happy about it. We tried as much as possible to accommodate their complaints and/or take actions to resolve them.

The overall performance of the students was acceptable, averaging over 85%. It is quite clear that the students could absorb the course material but they were having some difficulty in relating the course materials to real-world problems. The lowest SROI of 70% is indicative of the inadequacy of the purely academic version of Expedition. Contrary to our expectations, Primavera has restricted access to all the functions of the software. One can only view and go through the various projects built into the software. There is no way to develop your own project in the present academic version of Expedition.

The limited number of course objectives used in the course, historically, might have skewed the assessment process. It is quite obvious that a lot more work has been done but the assessment is very limited in scope. Prior to the introduction of the new approach to designing and delivering the Construction Management course, the course had been offered as an independent study and there was not adequate statistics collected to justify a comparative analysis. It was however agreed that the course design and delivery has to be enhanced to improve students learning.

Planned (Suggested) Revisions

As part of the continuous improvement process, the following corrective actions will be taken:

1. Dedicated Project Manager - work with a committed Project Manager to develop all the projects and their solutions prior to the onset of the course
2. Project/Contract Documents - obtain current copies of AIA and EJCDC Standard Contract Documents for use in the class.
3. Expedition – obtain a working copy of Expedition and do away with the academic version of the software. This will make lab sessions more meaningful and students will be expected to employ the software in the managing their projects.
4. Direct instruction – do away with or limit direct instruction and employ projects, tutorials and other course delivery methods to deliver course.
5. Assess Group Members – develop an assessment method for group members to eliminate/forestall free-rider tendencies of some of the students
6. Expansion of Course Assessment Criteria – introduction of more 3a-2k criteria into the course objectives to improve the assessment process.

Conclusion

Prior to the introduction of ABET's EC 2000 criteria, engineering programs are not required to include team work and real-world problem solving skills into courses. Students are not therefore fully prepared to enter the real world upon graduation. In the new era of ABET accreditation, various approaches have been employed by engineering programs to introduce students to real-world problems. The most popular approach is the use of a capstone project alone to introduce students to the formulation and solution of real world problems. The capstone approach has a number of shortcomings.

This innovative project-based course design and delivery was employed to bring a real-world project into the engineering classroom. The approach involved dividing a typical real-world project into manageable sub projects for the students to manage. Students were teamed up into groups of 4 or 5 and asked to manage a different aspect of the project about every other week. Some of the sub-projects stretched over 3 weeks. They presented their work in a typed format together with all the supporting documents at the end of each project phase. They were also required to make Powerpoint presentations to the class and answer a number of questions from the Project Manager and the Professor. At each phase of the project, students were given lectures, and other materials to aid the solution of the problems in the sub-project. ABET's 3(a)-(k) was used to assess the course outcomes. The average rating varied between 85% and 87%.

It is evident from this work that students can be made to learn real-world problem solving skills in the engineering classroom. This work has shown the use of bit-size project-based approach coupled with the appropriate guidance in the form of a project manager and course work can be beneficial to students. It however requires additional resources and a lot of dedication on the part of the Professor, Project Manager and the students to make it work well. This innovative approach can be used together with the traditional capstone course to enhance the problem solving skills of students. This course may however serve as the capstone equivalent for Construction Management students. Construction engineering students are required to take this course in their final year of studies to prepare them for the construction industry.

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