

AC 2007-2533: USING CASE STUDIES TO TEACH INTRODUCTORY DESIGN CONCEPTS TO FIRST YEAR ENGINEERS

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Using Case Studies to Teach Introductory Design Concepts to First Year Engineers

1. Introduction

This paper presents the authors' first experiences with delivering case studies on a large scale (1000+ students). The authors used multimedia (mostly video) in place of in-class delivery to gauge its effectiveness at such a large scale. The results in terms of the student responses to a questionnaire and their performance on the case studies are presented. These results will be used to improve the case studies. It is hoped that this paper will give others a glimpse into the process of continuous improvement of case studies. To that end temporary weaknesses in our products and processes are explored in detail.

A new group called the Design Case Studies Group (<http://design.uwaterloo.ca>) has been created in the Faculty of Engineering at the University of Waterloo to create case studies for use in courses throughout the curriculum. A good case study represents reality: a real situation (context), a real problem faced by an engineer, and uses real data. The following criteria are also used in evaluating a case study for use in a course:

1. Contains incomplete/extraneous data
2. Requires judgment and evaluation as well as analysis
3. Requires problem formulation and refinement
4. Involves an element of Design
5. There is no single correct solution
6. The company's actual solution is available for comparison with student work

Cases must map well onto the curriculum, and are most effective if they can be used in more than one course. The group's first case studies were presented in the Fall of 2006, and are the subject of this paper. The purpose of the case studies was to introduce the engineering design process to first year students in every Engineering department. This is consistent with other "Engineering in Context" approaches to first year engineering courses. [1, 2, 3, 4]

Two case studies were chosen: A *Hydro Quebec* case study which involves selecting from among alternative energy sources, and an *Engineers Without Borders (Canada)* case study on drinking water supply.

The first case study was used to introduce the engineering design process and its terminology, and the second case was used to give the students hands-on experience working through the steps of the engineering design process.

In the second case, the students ultimately had to enter and run an Excel simulation to determine the *optimum size* for a rainwater storage tank that would carry an average household through drought periods using the excess rainwater collected in wetter periods.

At the end of each case study, the students were presented with an *Engineering Design Process Summary* document, outlining the design steps they followed. The *Summary* document for the EWB case study is shown in **Table 1**. The students were encouraged to fill out a blank summary form (available on-line at: http://design.uwaterloo.ca/cases/Drinking_Water/summary) when doing their own design projects to emphasize the design process.

1. Needs Analysis:	Problem Statement:	Provide drinking water to villagers in Mavukall
	Order of Magnitude Calcs:	Annual drinking water demand is met by runoff rain water supply in worst year
	Requirements:	Safe to drink. Cost suits villagers' incomes.
	Constraints:	Amount of water available from any given source is limited.
	Ranking Criteria:	<i>Quality of Water; Legalities of Using Source; Impact on Others; Cost/Ease of Operation/Maintenance; Capital Cost; Quantity of Water</i>
2. Conceptual Design:	Brainstorm Concepts:	Rainwater Harvesting; Dam Stream; Hydro Reservoir; Spring; Well
	Rank Concepts:	(1) Rainwater Harvesting, (2) Hydro Reservoir, (3) Spring, ...
	Select Concept(s):	(1) Rainwater Harvesting
3. Preliminary Design:	Select Components:	Storage Tank, Gutters, Down Pipe, Gate Valve, Filter Unit
	Simplified Sizing:	Storage Tank needs to hold ~4 months of demand
	Simplified Analysis:	4 x 2880 litres = 11,520 litres
4. Detailed Design:	Materials & Assembly:	Ferrocement chosen after <i>Detailed Sizing</i> done
	Detailed Sizing:	Simulation: Tank Size: 100% Reliability 13,400 litres 95% Reliability 10,000 litres 90% Reliability 8,100 litres
	Detailed Analyses:	Simulation: Tank Size: Total Cost 100% Reliability 13,400 litres \$813.50 95% Reliability 10,000 litres \$677.50 90% Reliability 8,100 litres \$601.50
	Solution Statement:	The chosen design is to use Rainwater Harvesting with tanks constructed from ferrocement, and where villagers are given a choice in tank size from the above table, depending on their means and their comfort level for reliability.
5. Implementation:	Manufacturing & Distribution:	Locate storage tank in shade. Train users on sanitary use, and maintenance. Keep away from pedestrian traffic to avoid damage.
6. Operation:	Actual Use & Maintenance:	The gutters should be kept clear of debris and wildlife (guard should be used). The filter should be kept clean. The tanks and pipes should be checked for leaks periodically. Proper water treatment procedures with chlorine should be followed to ensure the water is safe to drink at all times.
7. Retirement:	Deactivation & Disposal:	The concrete could be broken down into small pieces and used as road bed. The iron bars could be sent to a scrap metal yard for recycling.

Table 1: “Engineering Design Process Summary” for EWB Case Study

The engineering design process looks linear here to emphasize its methodical nature, but emphasizes iteration in each phase. Each phase has a step “**Revisit Needs Analysis (and other phases) based on new information about Requirements, etc.**”

Each step has the definition of its term in the entry field for the step. For example, for **Ranking Criteria** it says: “**Identify the criteria on which potential design solutions will be ranked.**”

The case studies were accessed by the students through our on-line course management system, Angel (<http://angelllearning.com>). The steps the students followed are outlined in **Table 2**.

Step 0: Introduction

Step 1: Design Case Study (#1)

Step 2: The Engineering Design Process

Step 3: Engineers Without Borders (EWB)

Step 4: EWB Design Case Study (#2)

Step 4.0: Review Questions

Step 4.1: Needs Analysis

Step 4.2: Conceptual Design

Step 4.3: Preliminary Design [Needs EXCEL]

Step 4.4: Detailed Design [Needs EXCEL]

Step 4.5: Implementation, Operation, Retirement

Step 5: EWB Case's "Engineering Design Process Summary"

Step 6: Your Opinion of these Design Case Studies [Optional]

Step 7: Your Consent to Have Your Written & On-line Work Studied [Optional]

Table 2: Steps in *Hydro Quebec* and *Engineers Without Borders* Case Studies.

Steps 1 and 2 presented the *Hydro Quebec* case study in narrated slide show format. Step 1 presented the case study in colloquial form. Step 2 introduced the steps of the engineering design process, and used the Hydro Quebec case as the example for each step.

Steps 3 and 4 presented background information on the *Engineers Without Borders* case study. Step 3 was a video produced by EWB themselves. Step 4 presented the case study in narrated slide show format, with emphasis on the global problem of water supply.

Steps 4.1 – 4.5 took students through the engineering design process for this case study with a series of 23 questions they had to answer, along with feedback after each question. Here are three representative examples of the sort of questions asked:

1. At the beginning of **Conceptual Design**, students were asked:

“Should we go ahead with Rainwater Harvesting as our basic design [concept]?”

It was assumed that most students would answer “Yes”. Therefore the feedback was:

“A natural tendency of designers that we want to avoid is going with the first idea that we think of, and turning on ‘blindness’ to all others ... Let’s brainstorm to get other ideas out on the table ...”

2. This led to the second question:

“Brainstorm other water sources that might be available. Be as thorough as you can ...”

with feedback in the form of a new question:

“Let’s compare your list to ours ...”

Check off the "ideas" or "design concepts" that you thought of above:

- A.** Rainwater Harvesting
- B.** Stream / River
- C.** Reservoir for Hydroelectric Station
- D.** Spring
- E.** Well
- F.** Lake

3. In the **Detailed Design** phase, the first question read:

In this step we will simulate the amount of water in the storage tank using 20 years of rainwater data. We will try different storage tank sizes until we find the smallest storage tank that does not go dry during any month of the simulation:

1. **[Right-click]** and **[Save]** the following video:

[Excel instructional video](#)

which will show you how to simulate **the amount of water contained in the storage tank every month for 20 years**, for a proposed storage tank size.

2. **[Right-click]** and **[Save]** the following Excel file containing 20 years of "Rainfall" data for Mavukall (in columnar form) and ***open it in Excel*** and use it as a starting point as instructed in the video:

[Columnar Precipitation Data.xls](#)

3. View the video. Work through the steps in the video as they are presented so as to recreate the spreadsheet in the video.
4. Through trial-and-error try to find the smallest tank size needed for the 100% reliability scenario. Find the size to the nearest 100 litres (e.g. 12300 litres).
5. Record the resulting tank size here **and** on a piece of paper for later plotting (of tank size vs. reliability.)

The feedback read:

Your result should have been about 13400 litres for 100% reliability.

2. Data Analysis

Our objectives in data analysis were two-fold. First, find flaws and good points in the content and/or presentation of the case studies. Second, assess how well the students had learned the essentials of the engineering design process and how to apply it.

At the end of the case studies, the students were asked for their opinions in a detailed survey with multiple choice and open-ended questions. The results are discussed in detail below.

Of interest was the students' impressions of these first case studies, in particular if they helped them learn about the engineering design process. Student engagement and performance were also examined.

Many of the courses in which the cases were used also had the students complete a design project and final report later in the term. Of these, three courses (Civil Engineering, Environmental Engineering, and Mechanical Engineering) required that the students complete an accompanying "Engineering Design Process Summary" document outlining the steps of the engineering design process that they followed for their designs.

This included a total of 366 students. Of these, 92 students (25%) gave permission for their on-line and written work to be evaluated for the purposes of this research. Their "Engineering Design Process Summary" documents for their later design projects were marked by one of the authors for consistency.

Several types of data were collected. These were interpreted to provide information on attitude, opinions and performance.

- **Attitude** to the case studies was measured based on the correct response to key questions. (92 students.)

(Note that the case studies were not assigned marks. But this was offset by the fact that Steps 1 to 4 were videos that they could view at home (total 30 minutes), and Steps 4.1 to 4.5 were usually worked on (individually) during a scheduled 2-hour

tutorial in a computer lab. Therefore, they had minimal additional homework as a result of the case studies.)

- **Opinions** on the effectiveness of the cases studies and the use of multimedia, both positive and negative, were assessed directly with a survey. (103 students = 28% of 366.)
- **Performance** was based on an evaluation of the “Design Summary” documents submitted later in the term to accompany design project reports. (40 of 92 “Design Summaries” were used.)

2.1. Attitude

Attitude was measured based on whether the students submitted the correct answers after carrying out intricate Excel simulations. It was assumed that if they had worked this deeply into the case study, and had proceeded with sufficient care to obtain an accurate result, then they had taken the case studies *seriously*. Out of 92 students, 77 students (84%) worked diligently enough to get the correct answer in the simulation. This indicates that a large proportion of the students took the case studies seriously.

2.2. Opinions

Students were asked their opinion of the case studies using the following statement: “*Case studies are an effective means of learning about the engineering design process.*” Possible comments were: Strongly Disagree (SD), Disagree (D), No Opinion (N), Agree (A), and Strongly Agree (SA).

A similar statement was used to assess the effectiveness of the multimedia presentations: “*Interactive multimedia (videos, explorations) is effective in making case studies about the engineering design process more engaging*”, with the same comment options.

The overall results are summarized in **Figure 1** on the following page. The overwhelming majority of students “agree” (A) or “strongly agree” (SA) with both assertions. Students generally believe that case studies are an effective means of learning about the engineering design process, and that multimedia makes the case studies more engaging.

2.3. Attitude vs Opinion

Table 3 on the following page shows the number of students in each category for the question relating to the effectiveness of case studies. Of the 92 students who gave permission to use their work, opinion data was available for only 77. Also included is the number of students in each category who performed the simulation correctly. This was divided by the number of responses in each category to obtain a percentage.

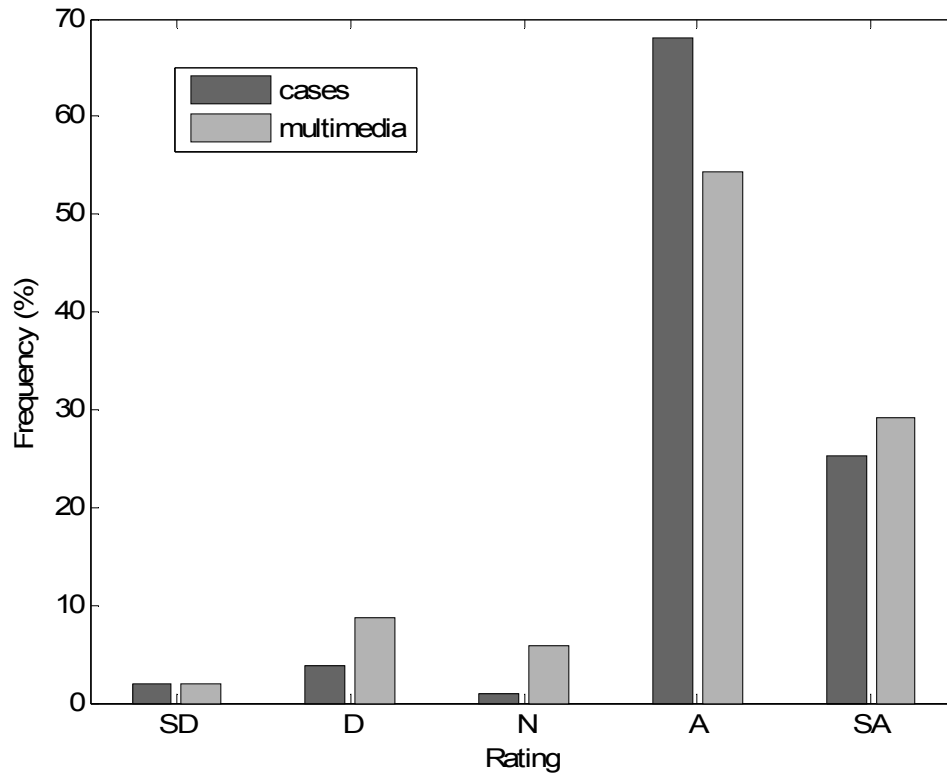


Figure 1: Student opinion regarding the effectiveness of case studies and the multimedia presentation.

No consistent trend is evident. From 81% to 87% of those students who agreed or strongly agreed with the effectiveness of cases also obtained the correct simulation results. Too few students disagreed with the statement to draw definitive conclusions, and their responses were inconsistent. More data needs to be considered.

	SD	D	N	A	SA	Overall
Total	1	2	0	53	21	77
# Correct	0	2	0	46	17	65
Percentage	0%	100%	-	87%	81%	84%

Table 3: “Case studies are an effective means of learning about the engineering design process”, versus students with the correct simulation result.

2.4 Performance

Performance was based on students’ understanding of the design process, measured using their completion of the “Design Summary” document for their design projects. Common errors were

(1) students confusing “Requirements” with “Constraints”, and (2) students confusing “Requirements” with “Ranking Criteria”. Problem statements were generally entered correctly.

The data was processed in terms of the number of errors in these documents. **Table 4** presents results for 20 Civil/Environmental Engineering students and 20 Mechanical Engineering students. For both groups of students, over half made *at most one error*, and about three quarters made *at most two errors*. While not stellar, these results indicate a certain comfort level and mastery of the engineering design process.

Errors	Civil/Env	Mechanical
0	8	4
1	4	8
2	2	5
3	4	2
4	2	0
5	0	1
Total	20	20

Table 4: Performance evaluation for the “Design Summary” document for Civil/Environmental and Mechanical Engineering Students.

3. Other Student Opinions

The students were asked further questions on the survey, concerning the pace of steps, whether sufficient background information was included, and open-ended questions regarding their opinions of the case studies and the multimedia used.

3.1. Pace of Steps

Students were asked to evaluate the pace of Steps 1 to 4.5 (see Table 2). Their responses are summarized in **Table 5** on the following page. One standout “slow step” was the *Hydro Quebec EDP* (engineering design process), which recaps the Hydro Quebec Case while filling out a “Design Process” document. The audio needs to be re-recorded at a faster tempo, the script tightened up, and the visual effects need to be more extensive, according to student comments presented below.

The other standout “slow step” (as remarked by 31% of the students) was *Preliminary Design*. This step is actually relatively short, except for step-by-step video instructions on creating an Excel graph of rainwater runoff versus time. The problem is likely related to the fact that it was not easy to go back to the previous step in the video-based instructions.

Step:	# Slow	# Fast
1. Hydro Case Study (<i>video</i>)	21	9
2. Hydro E.D.P. (<i>video</i>)	31	7
3. EWB Background (<i>video</i>)	10	2
4. EWB Case Intro (<i>video</i>)	5	5
4.1 Needs Analysis	21	3
4.2 Conceptual Design	18	7
4.3 Preliminary Design	32	14
4.4 Detailed Design	21	25
4.5 Implementation, etc.	10	12

Table 5: Student response regarding the pace (too slow or too fast) for the steps in the case studies presentation. A total of 103 students were tabulated.

Many students found the *Detailed Design* stage too fast. Part of this step included lengthy and detailed video instructions on setting up a simulation (of the amount of water in a storage tank of a given size at the end of each month over 20 years). An almost equal number found the step too slow. This can likely be explained by the fact that a good portion of the students already was familiar with Excel, while another good portion was relatively unfamiliar with Excel.

One surprise was the *EWB Background video*, a professionally produced 10-minute introductory video on *Engineers Without Borders (Canada)*. It had relatively few responses either way, despite its considerable length. Length was a concern when it was added to the case studies, but now that concern has been allayed.

3.2. Background Information

The students were asked to comment on whether “*Sufficient background information was provided about the case study in Step 4: EWB Design Case Study (#2)*”.

The case study was written to present the global issues of drinking water to motivate the students. This was followed with minimal basic information describing “rainwater harvesting” approaches. The results are summarized in **Table 6**.

About one fifth of the students either disagreed (D) or strongly disagreed (SD), so additional information on “rainwater harvesting” may be justified.

SD	D	N	A	SA	Total
1	18	13	57	14	103

Table 6: Student responses to statement: “*Sufficient background information was provided about the case study in Step 4: EWB Design Case Study (#2)*”

3.3. Likes and Dislikes

The survey concluded with two open-ended questions: “*What did you **like** about learning about the engineering design process using the two case studies?*”, and “*What did you **dislike** and how would you improve it?*” The replies of about 100 students were examined. The top three things they **liked** were:

- (1) **Learning about the design process** (17 students). *See the representative comment below where the student came away with not only an appreciation for the overall process but also the potential of the engineering design process to improve lives.*
- (2) **Using real-world applications** (16 students)
- (3) **Being engaged by multimedia** (13 students)

Here are representative comments:

- (1) “I liked how it improved your knowledge of what people face and how their lives can be improved with the help of engineering techniques. I also liked how it taught you to open your mind so that you can see there are many more problems or solutions to problems than you can think of.”
- (2) “The case studies gave concrete applications of engineering. They were actually quite interesting, and introduced a variety of issues concerning engineering design (cost, reliability, possible problems, etc).”
- (3) “It was interactive and helped me learn better, whereas if this information was taught to me in a lecture, I probably would have slept through half of it. It was interesting also since the actual design problem was interesting, it took actual thought to think of the design etc. The explanation in all of the videos was well done.”

The top three things they disliked were:

- (1) **Lack of video controls like rewind on some videos** (14 students). *This need was not anticipated during development of the case studies, or observed during usability testing on 5 subjects.*
- (2) **Unclear wording of some of the questions** (11 students). *Questions were left as open-ended as possible.*
- (3) **Voice of one of the narrators compared to the other** (9 students). *Originally just one narrator spoke, and there was no problem. Then the second narrator was added to read an example after each point the first narrator made. There was too much contrast in the pace of the two speakers.*

Here are representative comments:

- (1) "The part I disliked was that during the Excel instructions if you missed something in one step it was necessary to watch the entire tutorial over again in order to see it. It would be much more accessible if you could move back and forth between steps."
- (2) "Many of the 'essay response' questions were vague. I became frustrated at how I provided well thought out answers just to find out that the question was asking something different. To improve such problems, I would include extremely specific examples to accompany the question."
- (3) "The only thing that I disliked was the male voice on some of the videos. His voice was very monotone, and made that part of the case study difficult to follow along with. More enthusiasm, and punctuation would be nice. (Sorry if I offended anyone.)"

4. Conclusions

A pilot project implementing case studies with multimedia elements for over 1000 first year engineering students was undertaken. An assessment of data on attitude, opinion and performance resulted in the following conclusions:

- A large proportion of students took the case studies seriously, as measured by the (care they showed to get) correct answers to the most challenging part, which involved setting up Excel simulations.
- Students generally believed that case studies were an effective way of learning about the engineering design process, and that multimedia made the case studies more engaging.
- Students had a certain comfort level with the engineering design process later in the term, which may in part be attributable to the case studies. 50% made *at most one* error when completing their own "Design Summary".

An examination of the results from other survey questions resulted in the following conclusions:

- The pace of a few of the videos needs to be improved; some were too slow and some too fast.
- More background information could be provided for the EWB case. Additional graphical materials on India and "rainwater harvesting" would be appreciated.
- The students especially liked: (1) learning about the engineering design process, (2) using real-world applications, and (3) being engaged by multimedia.
- The students especially disliked: (1) the lack of video controls like rewind on some videos, (2) unclear wording of some of the [open-ended] questions, and (3) the voice of one of the narrators when juxtaposed with the other narrator.

Overall this was a good learning experience deploying case studies to a large group of students using multimedia elements. It confirmed some expectations about what might work, and

provided valuable feedback on what needs to be done to improve the case studies and multimedia.

Finally, the Design Case Study Group learned that case studies delivered via multimedia to 1000+ students can still be a very motivating and engaging way for the students to learn more about the engineering design process in practice, beyond what is introduced in lectures.

5. References

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