AC 2011-111: DISK BRAKE DESIGN CASE STUDY IMPLEMENTATION METHOD AND STUDENT SURVEY RESULTS

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Oscar worked at the Canadian Forces Department of National Defense failure analysis lab, where he was the Canadian Project Officer for an international program on F/A-18 bonded repair, and prior to that, a Research Engineer at the Canadian Space Agency. Oscar designed and qualified space flight hardware for a space experiment for Space Shuttle Flight STS-52 in 1993.

Earlier in his career Oscar led the design and development of products employing composite materials at Owens Corning Canada and contributed to the development of novel production machinery for the fottwear industry with Bata Engineering.

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Disk Brake Design Case Study Implementation Method and Student Survey Results

Abstract

A design case study featuring a disk brake design for large earth-moving trucks was implemented in a senior (4^{th}) year mechanical engineering design course at the University of Waterloo (Waterloo). The case study was given to one class of 35 students in the spring term of 2009 and then to a second class of 27 students in the spring term of 2010. The case study was given as an in-class exercise over two lecture periods.

The design case study was designed and written in collaboration with an industry partner, Hitachi Construction Truck Manufacturing Limited (Hitachi) of Guelph, Ontario, Canada. The case study's primary learning objective was for students to design the front disk brakes of a mid-range model truck while working in teams of about 5 persons. The implementation method had the students design the brakes after a lecture on disk brakes and using information given in the text. They were then asked to design the brakes using information provided by a commercial manufacturer and supplier of brake calipers. Students were asked to present their designs as sketches on the board. A class discussion then followed. The brake design was unique in that the actual solution required the use of more than one caliper per disk.

A survey was given to the students immediately after the case study exercise. The results of both implementations revealed that 95 % of the 40 respondents agreed or strongly agreed that the case study was an engaging application while 75 % perceived that it improved their understanding of the concepts taught. Approximately 60% of respondents agreed or strongly agreed that group discussions helped their understanding of the concepts taught. About 80% of respondents agreed or strongly agreed that classroom discussions helped their understanding of the concepts taught.

The survey also asked the students to express what they especially liked/disliked about the case study, what they would suggest to improve the case study and what advantages the case study had over traditional lectures. Students reported that they enjoyed the real life application of the theory but also reported having difficulty with the open-endedness, lack of complete information and lack of time provided to do the case study.

Introduction

Waterloo Cases in Design Engineering (WCDE) was established to enhance the teaching and learning of engineering design using case studies. The primary source of case studies is from student work-term reports that are generated after the students' co-operative term experience in industry. Typically the student employer is contacted during the initial stages of the development activity, and provided the opportunity to pre-approve content and suggest changes. Both the student and employer must approve the final case before release, to ensure authenticity.

A second method of developing cases studies is to approach an industry partner directly for a design experience that they would deem meaningful for engineering education. In this case, the contribution to the education is provided largely from the industry partner perspective, as opposed to a student experience perspective. This represents an excellent opportunity for our partners to provide feedback, in an actionable way, to our engineering curriculum and students' education. It represents their view on what is currently important to them. When soliciting input from industry partners, there are often recommendations that they make that may or may not be implemented in the curriculum. This mechanism and method represents an actionable and timely method to have the industry educational recommendations implemented.

Background

The process of education has been described as a two step process [1]; namely, the delivery of knowledge, and the assimilation of knowledge by the learner. For engineering education, a third step is required – the application of knowledge in uncertain situations and under constraint.

Case studies continue to be used to provide contextual opportunities for students to apply newly acquired knowledge [1–10]. They are proven mechanisms for fostering active learning and for allowing students a chance to integrate domain knowledge and procedural knowledge to find and solve real problems.

There is legitimate concern regarding the state of engineering education in North America, and its capability to educate engineers required for the future. A number of reports have been issued [11, 12] suggesting that the current curriculum designs are inadequate in preparing students for professional practice. They indicate that current curricula emphasize engineering science, often at the expense of engineering design and the integration of professional skills and learning of important behaviors. Recommendations include incorporating a professional spine in the curriculum, whereby students may have an opportunity to integrate their knowledge in a contextual environment. A second recommendation outlines the need for students to make connections between theory and practice and to develop the thinking skills required for engineering practice. This requires an inductive, as opposed to a deductive, approach to teaching and learning.

The integration of professional identity, knowledge and skills requires that students have an opportunity to experience engineering practice, through so-called *approximations to practice*. Often this means exposing students to laboratory or design project teaching methods (they are different). A recent study suggests that students who are exposed to enquiry - based learning develop early confidence that results in better performance in subsequent years of study [13].

Surveys of industry and university alumni consistently point to the importance of design, communication and teamwork skills, but more importantly, students' ability to make sound judgments in conditions of technical, commercial and sometimes ethical uncertainty. Industry values student learning in rich contexts, and they acknowledge the value of supporting extracurricular student teams.

The incorporation of rich, contextual components is desired, but not at the expense of engineering science fundamentals. This presents a conflict between retaining this essential engineering science component of the curriculum and incorporating a professional, practical backbone that might include problem-centered learning, or project-based learning.

Case studies and the case method of active learning, represent a proven and feasible mechanism to enhance curricula without major curriculum redesign. They are very flexible mechanisms that can be incorporated into any course, and any delivery method. They provide rich context, and show promise as an assessment tool as well.

The use of case studies can be ubiquitous, yet innocuous. They can be deployed as in-class exercises, of short or long duration, as an assignment or as a term project. The exhibits could include multi-media, engineering data and documentation, or hardware (failure analysis case studies).

Typically case studies require that students work in groups, and this, naturally, fosters teamwork and communication skills, while at the same time enhancing the learning of each individual student.

Outcome-based assessment has been introduced as an accreditation requirement both in the US [14] and Canada [15]. Certain abilities and graduate attributes, while very important, are difficult to assess in a quantifiable manner using existing assessment methods. Case studies show promise in this area.

However, what case studies offer, based on our own experience and the experience of many business, law and medical programs, is an opportunity to apply theory in new contexts, and to continually practice problem (finding and) solving skills.

Case Study Development

WCDE has developed a case study development method that is proven and sustainable [16].

A need was identified by the lead author, the instructor of a 4th year mechanical engineering design course, to have students design a clutch or brake assembly. This was the primary learning outcome identified. The course is currently delivered with limited opportunity for the students to synthesize (i.e. design) in context. The instructor's industrial experience identified a need to extend the knowledge gained by the students via a lecture on the theory and an example problem, to a so-called approximation to practice – a case study. It was important that the students be able to perform this activity in a classroom setting and in groups. The development of teamwork skills was also identified as a learning outcome (but not explicitly assessed, other than observations of the groups working in class). A third learning outcome was for the students to experience the difference between theory (from the textbook) and practical application (how it was actually done in industry, in this instance) in designing a braking system.

A case plan was generated, per the development process referenced above, and this plan was presented to the industry partner. Background information was provided by the industry partner on their brake design, including their specification, standards used for design, calculations used for their design, braking system description, truck product information, business information, and general company information. Truck product information, an internal brake engineering specification and a regulatory standard [17] used for design, were key exhibits that formed part of the case study.

The case study was generated and reviewed by the industry partner. WCDE received permission to use the case study, limiting the initial distribution to Waterloo [18].

Case Study Implementation

The case study was given to one class of 35 students in the spring term of 2009 and then to a second class of 27 students in the spring term of 2010. About 50% of the 2009 class attended a field trip to Hitachi where they were given a presentation on the product and the braking system. They were also given a tour of the manufacturing facility where they could witness the manufacture and assembly of the trucks. It was planned that students would not be shown any of the brake assemblies, since the case study was designed to challenge their notion that a disk brake assembly contains only one (1) caliper per assembly; typical brake assemblies in this industry were comprised of two (2) and sometimes three (3) calipers per assembly.

The case study was given as an in-class exercise over two lecture periods (a two hour period). A portion of one lecture period in the week prior was used to introduce the case study. Students were asked to read the case study prior to that lecture period. In this initial discussion the instructor moved through the case by setting the stage with the business, system-environment and product level context through an interactive classroom discussion.

The students were asked to describe the business that the company was engaged in, the yearly revenue of the business and the market share the company had as a supplier of earth moving vehicles. They were asked to describe the operating and service environment that the products were required to operate under, with an emphasis on operational safety requirements and harsh conditions of operation, and what the key interactions were between the product and the environment. They were prompted to describe the product ranges offered and the price of the products. The students were asked to describe the braking system design and intended operation, and what functionality was required. They were then asked to estimate the cost (not price) of a front disk brake assembly. The purpose of this question was to have them appreciate the importance of design-to-cost in a business context. Finally, the students were asked to determine, from the information provided to them, what overall braking force was required, acting on the truck centre-of-gravity, in kilo-Newtons.

In the interest of time, the instructor lead the students through a board exercise of deriving the required braking torque on the front and rear axles from the braking force determined above, and information provided in the exhibits again in an interactive class discussion.

The students were then given the task of designing the front disk brakes using the formulae developed and the tables available in the textbook by working in groups. The student teams were already formed for the course design project, and it was expected that they retain these same teams for the in-class exercise. Students were permitted to form teams on their own at the beginning of the course. Students were provided additional exhibits (not provided in the initial case study). One exhibit, shown in Figure 1, was a cross-sectional view of the front wheel assembly without the disk brake assembly shown. This was useful in providing the students the geometric constraints for the design task. All teams presented their designs on the blackboard and they were asked to explain any assumptions.

The students were then provided a technical data sheet for a disk brake caliper provided by industrial supplier brake calipers for large trucks [19]. Missing data or confusing presentation of the industry specific data was not initially clarified by the instructor, allowing the students to struggle with the information (or lack thereof) provided. The instructor then intervened as required, encouraged student teams to ask questions, providing guidance in order to move the student teams along with the task.

Students were asked to present their brake designs on the blackboard. All of the seven (7) student teams for the spring 2009 course offering presented designs that did not meet the braking requirements. One of the five (5) teams for the spring 2010 course offering presented a design that met the requirements (Figure 2).

Survey Method

A survey was developed to obtain the students' perceptions and feedback on the case study exercise and is based on previous experience using case studies and implementing them [20]. The survey that was used is presented in Appendix A. It was designed to obtain more detailed information than earlier surveys, on their responses to key questions by asking the question 'why?' for selected questions.

The case study and the survey were given at the end of the academic term, primarily because the content taught was delivered at that time.

Observations and Results

In both cases, the response to the case study implementation was generally favorable with students perceiving that the case study was engaging and that it helped them appreciate the relevance and to understand the specific course topics. Some students reported having difficulty with the open-endedness, lack of complete information and lack of time provided to do the case study.

Course Offering	Surveys Received	Students Available	%
Spring 2009	22	35	63
Spring 2010	18	27	67
Total	40	62	65

Table 1: Survey Response Rate

A total of 62 students were available to respond and 40 surveys were received in total. The response rate overall was about 65% and is summarized in Table 1.

The first survey question was design to assess the students' understanding of the intended learning objective for the case study exercise. Most recognized that the intended learning objective was to design a disk brake and to apply the engineering design method. Figure 3 presents the results of the number of occurrences of word phrases given in response to the question. In other words students provided more than one response and several word phrases to describe their understanding of the learning objectives of the exercise. It is interesting that some recognized that a learning outcome was to learn to design using regulatory standards as this was not an explicit learning outcome expressed in the case plan. Also an intended learning outcome was to foster teamwork and communication skills, and it is interesting that this was not recognized by the students as a learning outcome.

Most students (95%) agreed or strongly agreed that the case study was an engaging application of using the engineering design method to do brake design as shown in Figure 4. This is a very favorable result and not inconsistent with past case implementations. In their written responses, students reported that it forced them to apply recently learned concepts to a real world application. They reported that the group really had to think and had to work together through the problem. Finally, one student reported that it helped him see the context in which the brake disk theory and analysis was applied.

Figure 5 presents survey results for question 3. 78% of students agreed or strongly agreed that the case study helped them appreciate the relevance of the use of the design method to brake design. Students who strongly agreed reported that they saw the practical application of the theory, that they learned to work with information that you do and don't have, and that it showed the importance of understanding the fundamentals. One student's response was simply "now I know". One student strongly disagreed because he/she already understood the relevance, as did the one student who disagreed.

Figure 6 presents the results for question 4, where the students were asked report their level of agreement with how the case study helped them understand the application of the design method to brake design. 75% of students who responded agreed or strongly agreed that the case study helped them understand the application of the design method for brake design. Those that strongly agreed reported that the case study helped them learned from others in a group setting, that the group work helped to clarify things and that they were forced to go into detail in order to complete a brake design. Two (2) students disagreed, suggesting that they did not really understand the concepts before the case study was given, and the other reported that the exercise moved too fast, and that it left little time to absorb the material given.

Figure 7 presents the results for questions 5, where the students were asked to report on their level of agreement with how the group discussions helped them understand. The level of agreement on this agreement scale was more widely distributed than responses to previous questions, and to previous surveys conducted [20]. About 60% of students either agreed or strongly agreed that group discussions helped them. Those who strongly agreed reported that they were confused during the lectures, but working in a group clarified things, and that the discussion brought out their varied knowledge levels and experience. One student reported that students understand different topics better, and that discussion helps to spread the knowledge.

About 18% of those who responded disagreed that group discussions helped them to understand. Students reported that the group work in the classroom was unproductive, and that a classroom setting for project work is difficult. Students reported that there was not enough time to complete the task. Two students reported that the group work was unproductive because they were sitting with friends and it was more of a social time.

Figure 8 presents the results for questions 6, where students were asked to report their level of agreement with how classroom discussions helped them to understand the course topics. 80% agreed or strongly agreed that classroom discussions helped them to understand. This is an encouraging result and suggests that the instructor-student interaction method was effective. Students who strongly agreed reported that the discussion helped clarify any misunderstandings, that errors and shortcomings in the student designs were pointed out, and that insight from an industry perspective was given. One student reported that the instructor should engage in more classroom discussion prior to the group work as it was useful. One student disagreed because the group he/she was in made a lot of assumptions which were in some cases at “face value”.

Question 7 was posed to the students in order to determine what aspects of the case study they liked in terms of helping them to understand. The intent of this question was to obtain feedback on the case study design and the design of the implementation method in order to continuously improve this mechanism as an educational product.

Overall the students felt that the applied and practical nature of the case study was what they liked the most because it linked theory to practice. The method of allowing them to try on their own first was also something they liked overall, although some students reported having difficulty with this as is reported for the next question. One student reported that he/she liked the toy truck prop the instructor brought into class. Table 2 lists the students’ detailed responses to this question.

Question 8 was posed to the students in order to determine what aspects of the case study they disliked in terms of helping them to understand. Again the intent of this question was to obtain feedback on the case study and implementation method for continuous improvement purposes.

The most encouraging response was “none” – that there was nothing that they disliked (Table 3). However, most of the student responses suggested that information was lacking, that the problem was not well defined and that they had to make a number of assumptions. As was mentioned above, the case study was designed to challenge the notion that disk brakes are designed with one caliper. One response indicated that the student teams struggled to break away from this notion, as they felt that there was no reasonable answer available, and this left them questioning what they knew and how well they knew it. One student reported that they felt unprepared for the task. Also, one response suggested one team struggled to co-ordinate themselves to complete the task.

Question 9 was posed to the students in order to determine whether they had specific recommendations for improving the case study itself, or the implementation method (Table 4). In the 2009 implementation, students struggled with the lack of time provided for the case study. They also reported that they wanted all of the information, and in one response, suggested that the instructor not lead the students astray with an unreasonable answer. The adjustments to the 2010 implementation suggested that the student had a little too much time, and that they were in fact bored. In reality the amount of time allotted did not differ by more than 15%, and so this response is a bit puzzling.

Question 10 was posed to the students in order to have them express what advantages a case study activity has over traditional lectures (Table 5). The responses were revealing. Students reported that the case study was more engaging, that it kept them active and involved and that it stimulated thought. It allowed for creativity, and allowed them to visualize theory in an application. One student reported that they had to think and not just write, and that it allowed them to directly apply their knowledge.

Discussion

Clearly the results achieved in both implementations are favorable from the students' perspective. They provided specific reasons for why the case study and the case activity were engaging and why they believed it helped them to understand the concepts better. The fact that they struggled with the open-endedness of the case study exercise was not unexpected, since most of their learning experiences are by traditional teaching methods of lecture, example textbook problem, assignment and perhaps a laboratory or term project. They appreciated having an immediate opportunity to apply the new knowledge transmitted to them to a real application. If education can be defined as receiving knowledge and then assimilating it, the case activity may be thought of as providing an opportunity for receiving knowledge, assimilation it and applying the knowledge through the case method of learning.

Regarding the success of the student teams solving the problem, only one of the 13 teams was successful. Again, Figure 2 shows the results of team number 1 of the 2010 class, and the sketch showing that in fact two calipers are required, and feasible. Note that the team also placed the calipers 180 degrees apart, as would be expected in an optimized and effective design.

There is opportunity to fine-tune the implementation method. Normally students prefer to sit next to their friends in a class, and often those friends form their term project team members as well. There is an opportunity to experiment by forming groups more randomly with the thinking that this would challenge the development of teamwork skills (forming of a team) while minimizing the social aspect of getting together to perform a task.

Conclusions

Students reported that the case study, and its activities, was engaging and that it helped them to understand and reinforce the specific course concepts taught by traditional lecture methods. They also reported that group discussions, and in particular class discussions helped with their understanding. Only one (1) of the 13 teams was successful in breaking the paradigm of one caliper per disk brake assembly.

Recommendations

The case implementation method should be further optimized to make efficient use of the time available. In both implementations, two consecutive lecture periods were available, and required. The implementation could also be enhanced by inviting the industry partner to provide a presentation on the braking system design and the disk brake design, to further broaden and deepen students' understanding of the application in context.

No	Written Response to Question	Response to 'Why'
1	"Hands on approach, group work"	
2	"the start-to-finish scope of the case study"	"Nice to see a design project that doesn't deal with one small aspect of a larger design project"
3		
4	"evaluations of designs"	"Can see design weaknesses"
5	"relating mechanical drawing to calculations"	"in the industry problems are not started as in textbook problems"
6	"Interesting to see what other groups thought and what other mistakes were made"	
7	"the application of a case study in braking was useful"	"understood the factors required, what you can change, what you can't, requirements, constraints very helpful"
8	"using formulas to do real design"	"theory to practice"
9	"industry application"	"useful in future"
10	"calculations, investigating drawings"	"enjoy these things"
11	"unique"	"does not talk about giant dump trucks often"
12		
13	"professor explains preferred method after students attempt design"	"gives us a chance to try, on our own"
14	"following the design process from beginning to final part"	"helped to see where values are used"
15	"using real world information from suppliers"	"textbook info can be outdated and not reflect the real world"
16	"engaging in a practical problem - understanding assumptions"	"that's the expectation from an engineer"
17	"simple and direct"	"it wasn't overly convoluted with unnecessary details or requirements"
18	"real world application"	"more industry experience"
19		
20	"working with real world data, good context to potential design situation in real world"	
21	"group work was good"	"learned more a out brakes from group members"
22	"Application to real life"	"easier to understand when relate"
23		
24	"very thorough and built on prior stages well"	
25		
26	"working brake calcs"	good practice
27	"practicality of design"	
28	drawing dump trucks (seriously - pictures help convey concepts [1 pic = 1000 words - true!])	
29	using standards and specs to design	seems applicable to career in the future

30	course topics none. But focus on design was appreciated	it hasn't been taught in any other course
31	design selection	
32	real case, real drawings, real numbers	
33	dump truck application	it's interesting
34	I liked talking as a whole class to determine the solution	after getting to know the question each group participates instead of one or two people
35	you had us work through problems ourselves and then analyze the actual method chosen	it allowed us to compare our design against the real one
36		
37	I liked to toy truck you brought in	it reminded me of a simpler time
38	the detailed specifications and drawings handed out to the class	this is better than simply giving the relevant information directly as it simulates a work-place type problem
39	I liked being able to apply what was taught in lectures in an interactive setting	
40	trying to design our own brakes	idea of what parameters are included

Table 2: Student responses to Q7: "What aspects of the case study did you especially like in terms of helping you understand these specific course topics?"

No	Written Response to Question	Response to Question Why?
1		
2	"the materials given (drawings, etc.) were not labeled with some of the critical information"	"Frustrating trying to decipher the information given that would only be an easy phone call away in real life"
3		
4	"none"	
5	"leaving no option but an incorrect or unreasonable answer"	"we began to question what we know and how well we know it"
6		
7	"the vague description of the case and that some information was withheld that was required"	"was extremely hard to get started on the case"
8	"Too specific"	"one small part of mechanical design. Very specific component, very specific industry, instead of touching on general design in various fields"
9	"too little time to spend on each module"	
10	"group size"	"too many people trying to do one thing"
11		
12	"high number of assumptions"	
13	"don't get any examples before case study"	"don't really see where case studies are going until answers are taken up"
14	"the fact that required values were missing that needed to be obtained from supplier"	"we were unable to contact the supplier to converse on the topic"
15	"closely guarded industry secrets"	"felt like we were just guessing"
16	"problem was defined and described poorly"	"the objective wasn't clear"
17	"some of the spec sheet "	"blurry drawings, information unclear to us can

		be frustrating"
18	"moves too fast"	"felt like I was unprepared to handle the task"
19		
20	"I felt rushed, many calculations and assumptions to be made in a short period of time	
21	"reading spec"	"spec from Carlisle was confusing/misleading"
22	"spent a lot of time going in the wrong direction"	In real world you would have experience or exposure to these documents and know what info was within it. Instead in case study it was just difficult
23	too much of the information was hidden in the documents	
24		perhaps it should be framed as a 1-2 hour tutorial. I felt like the class was waiting to be led through it
25	this type of exercise works well in a focused, engaged class which I feel was lacking	just algebra
26	watching numbers being plugged, converting units	Boring
27	moved along very slowly	I need coffee, I think better at other times of the day
28	thinking on the spot. I want to understand the question before I blindly apply formulas	too distracting working in Ocean Rider design teams
29	rearranging of seating for groups - should be arbitrarily decided by numbers	if data was misinterpreted there wasn't a chance to correct
30	shortage of time	
31		
32	boring slow	unsure whether to assume something or continue looking (i.e. piston diameter)
33	information that was required was not included	more cases and more details can be covered or 2 examples in the same time
34	this is just one application	it kind of brought the class to a halt
35	some parts were a bit ambiguous and required professor support	it led to confusion with the calculations
36	there were some issues with the dimensions in the drawing	should have taken 30 minutes
37	took too long to solve - 2.5 lectures. The drawing used diameter symbol for radius	most of the designs are of the same idea, so it gets repetitive
38	having each group present their designs individually	
39	nothing it was fun	
40	none	In real world you would have experience or exposure to these documents and know what info was within it. Instead in case study it was just difficult

Table 3: Student responses to Q8: "What aspects of the case study did you especially dislike in terms of helping you understand these specific course topics?"

No	Written Response to Question
1	"allow a bit more time, clear instructions on what to do each group session"
2	"less small group work and maybe fuller open class discussion about all the decisions"
3	
4	"more background theory before activity"
5	"do not lead students astray with unreasonable answer"
6	
7	"give us all info and let students sort through it"
8	"touch on all aspects of design. A plastic housing of a cell phone is mechanical design. Form versus function not covered."
9	"lower the project expectation and letting groups spend more time on the study by their own"
10	"groups are a little smaller, step by step studies, scopes are often too large"
11	
12	
13	"show similar examples before doing case study"
14	
15	"A tiny bit more info up front, i.e. brake pressure"
16	"reduce the workload of the project and grade the case study"
17	"at the very least, better photocopied drawing"
18	"slow down, more time to absorb and reflect"
19	"allow a bit more time for group discussions"
20	"refine variables, make students guess on specific area instead of letting them waste time on unimportant issues (dimensional clearance)"
21	
22	"A little more direction in design"
23	have less documents and summarize some of the information i.e. wheel diameter etc. instead of having to locate in spec. having to look up in tables is fine, but just too many unfamiliar documents
24	
25	perhaps assign as a brief homework - in class was very slow
26	give feedback for questions asked
27	move along quicker
28	instead of a giant project, give us a few case study assignments for homework
29	distribute case and assign as reading…use less time in class
30	field trip to a mine. Dump truck drag race. Tractor pull? Monster jam!
31	converting everything into unit system to save time
32	include all required information, or make suggestions on what assumptions to make and why
33	I think they are fine. Full solutions on the blackboard are always helpful
34	tailor the case a bit to suit the classroom
35	
36	
37	don’t waste time on group discussion - individually and then take it up
38	
39	
40	none

Table 4: Student responses to Q9: “What suggestions do you have for improving this cases study, and its activities, in terms of helping you understand these specific course topics?”

No	Written Response to Question
1	"hands on learning, more entertaining, applicable to real world situations"
2	"real life application of principles emphasizes some of the real life encountered problems associated with using the methods/equations given in class"
3	
4	"can visualize how topic is applicable"
5	"real world cases of applied theory are always strong examples"
6	"traditional lectures are nearly as engaging and don’t really stimulate thought"
7	
8	"industry applications"
9	"groups are able to interact and learn from one another"
10	"keeps students active and involved"
11	"allows for creative thinking"
12	"active engagement which helps me focus…3 hours of staring at a blackboard is tough regardless of the material"
13	"more interactive"
14	
15	"actual real world scenario, not some made up fantasy textbook problem"
16	"able to visualize theory into application"
17	"engages us, shows us varied thought processes"
18	"better than regular examples. But not an equivalent substitute"
19	"it gives the course material real-world context and makes us think of the big picture"
20	"context to real-world"
21	
22	"hands on do it yourself - more examples before study needed"
23	actual problem from system level to end instead of just canned problems
24	
25	
26	try it out
27	very thorough procedure for those who need to take the time
28	hmmmm…..good question
29	see how design is conducted outside of academia
30	I have to think and not just write
31	less theoretical. It’s a more practical example which is close to workplace problems than classroom
32	
33	encourages self reasoning and use of the formula
34	practicality of the case study makes them worthwhile
35	it allowed us to directly apply our knowledge
36	the group aspect allowed for a quick resolution of confusion about certain topics instead of just sitting around
37	I see an application of the course material that I could have imagined on my own. I think there were more disadvantages in doing the case study
38	
39	
40	better understanding when used in actual application

Table 5: Student responses to Q10: “What are the advantages of suing this cases study, and its activities, over traditional lectures, in terms of helping you understand these specific course topics?”

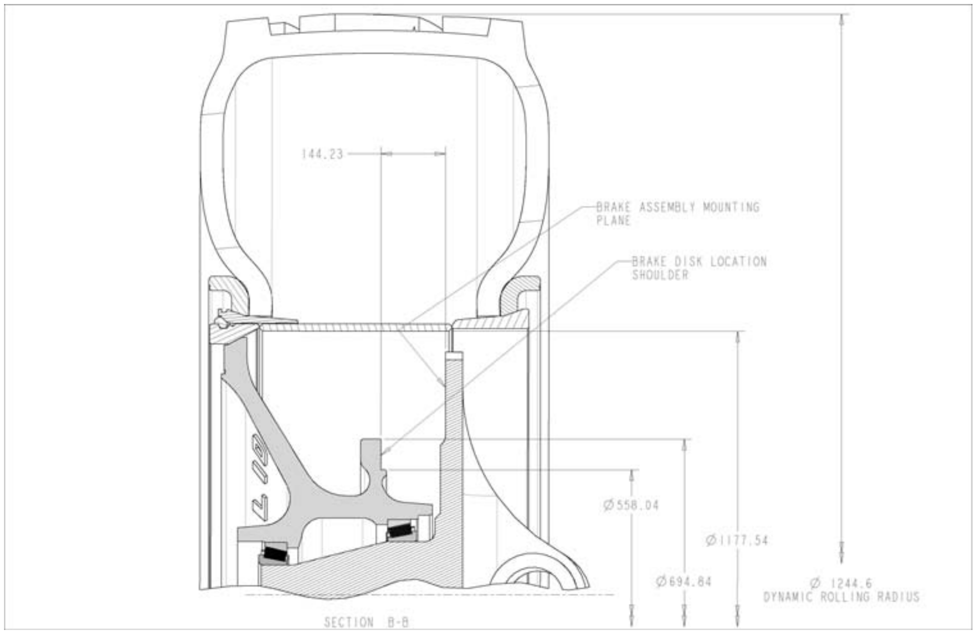

Figure 1: Truck front spindle cross-sectional view

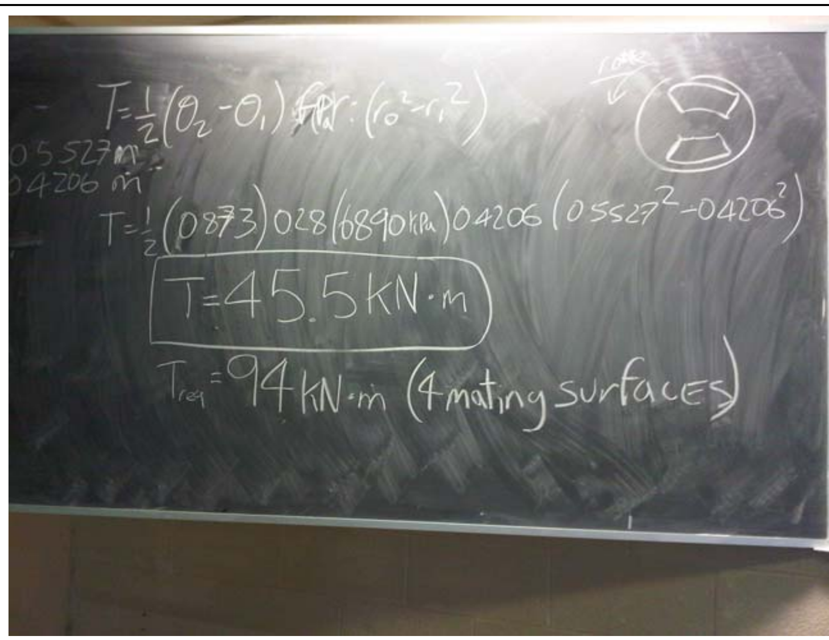

Figure 2: Disk Brake Design Solution showing the use of Two (2) Calipers

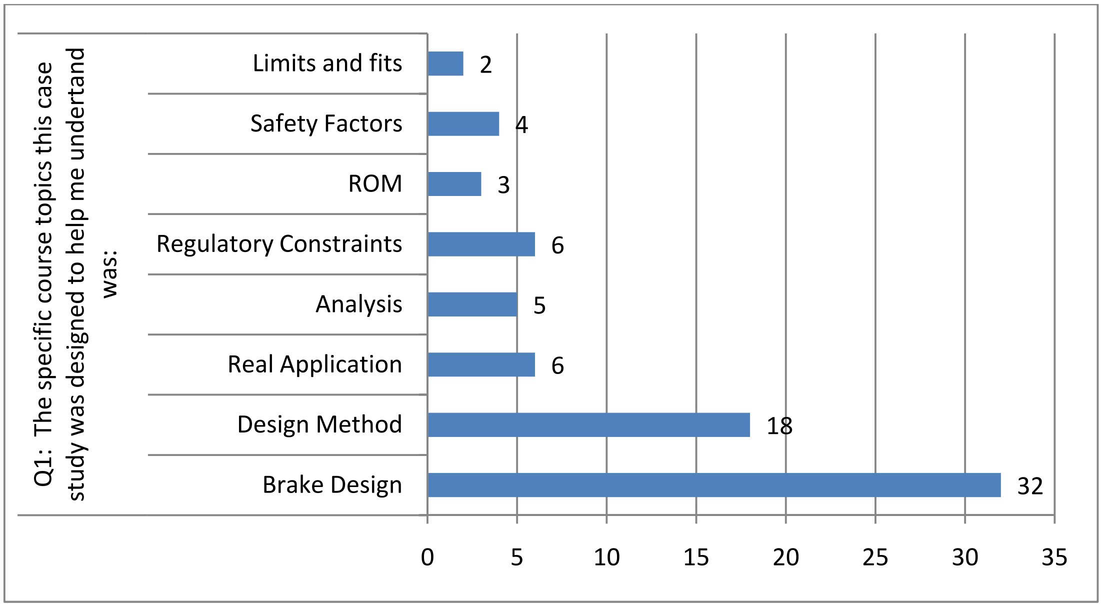

Figure 3: Number of word phrase occurrences in response to question 1

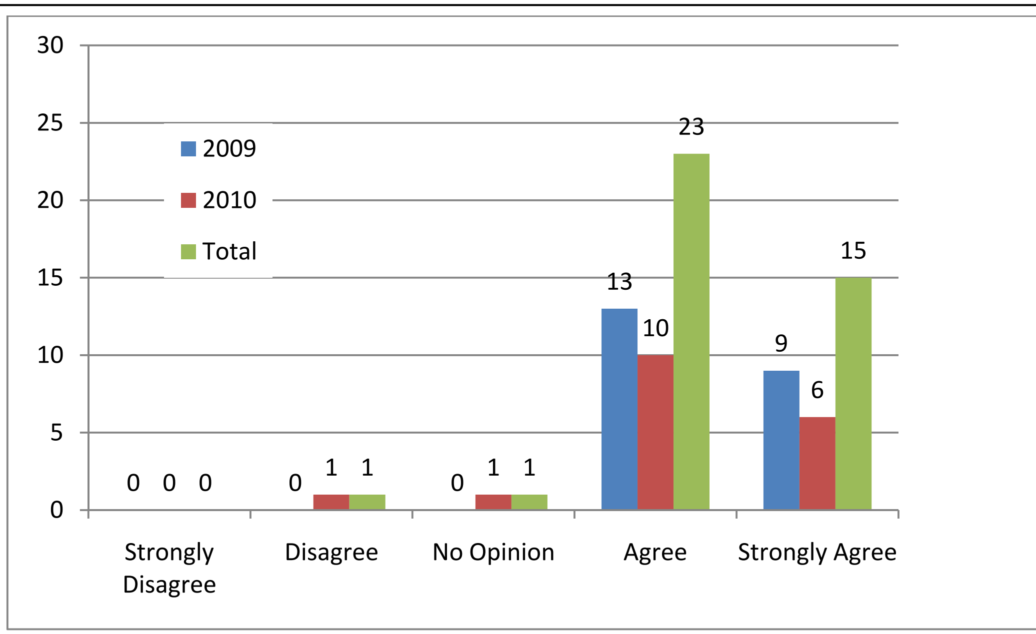

Figure 4: Q2 "This case study was an engaging application of the specific course topics"

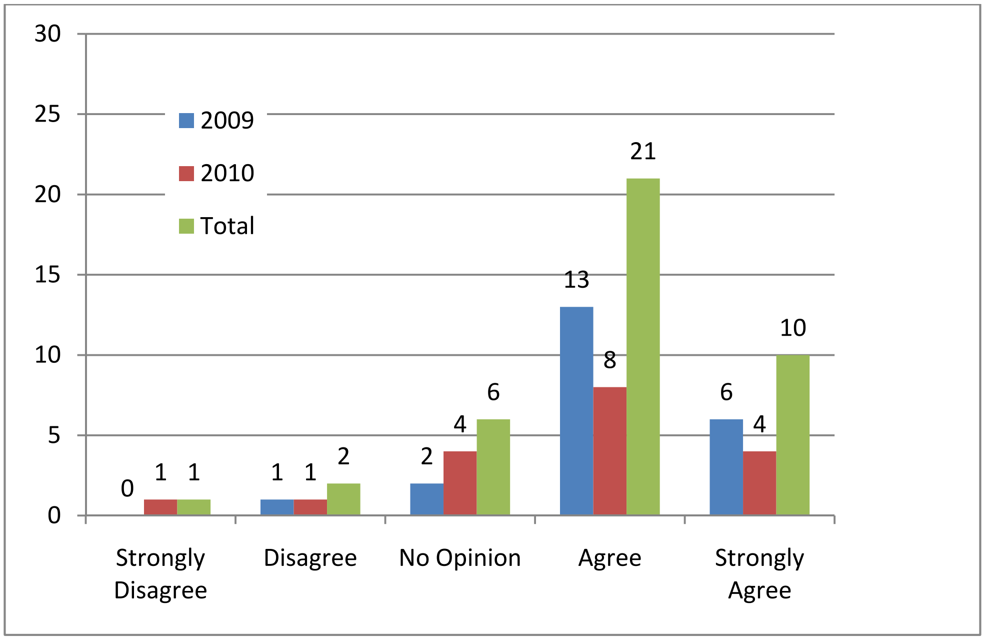

Figure 5: Q3 – "This case study improved my appreciation of the relevance of these specific course topics"

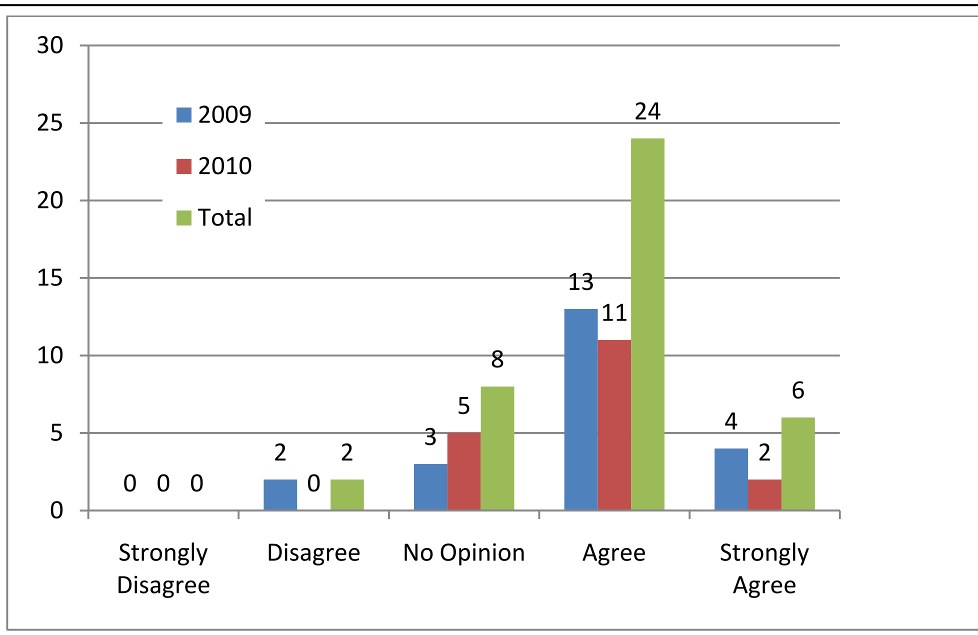

Figure 6: Q4 – " This case study helped me understand specific course topics"

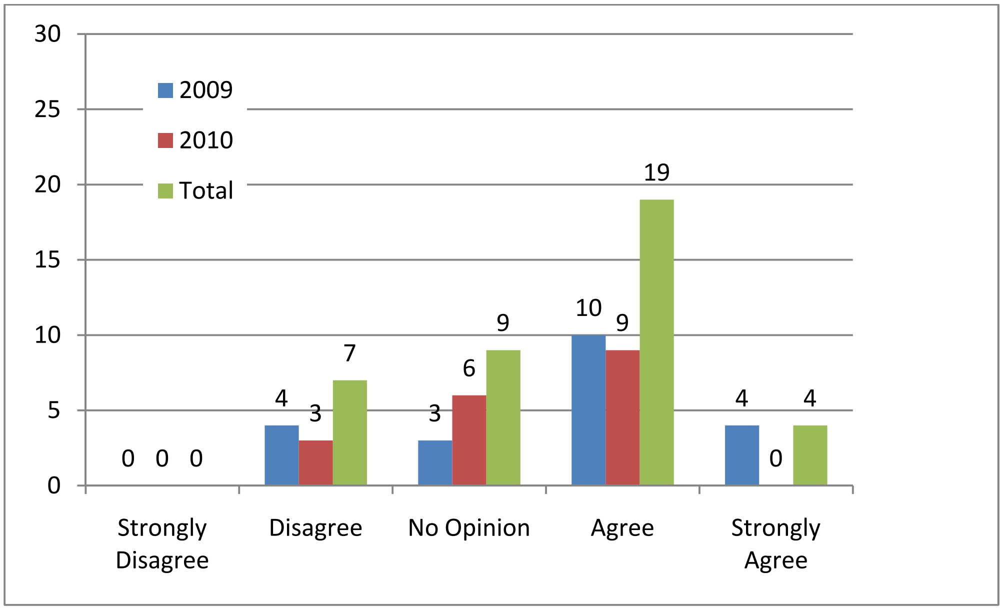

Figure 7: Q5 - "Small group discussion(s) of the case helped me understand the specific course topics"

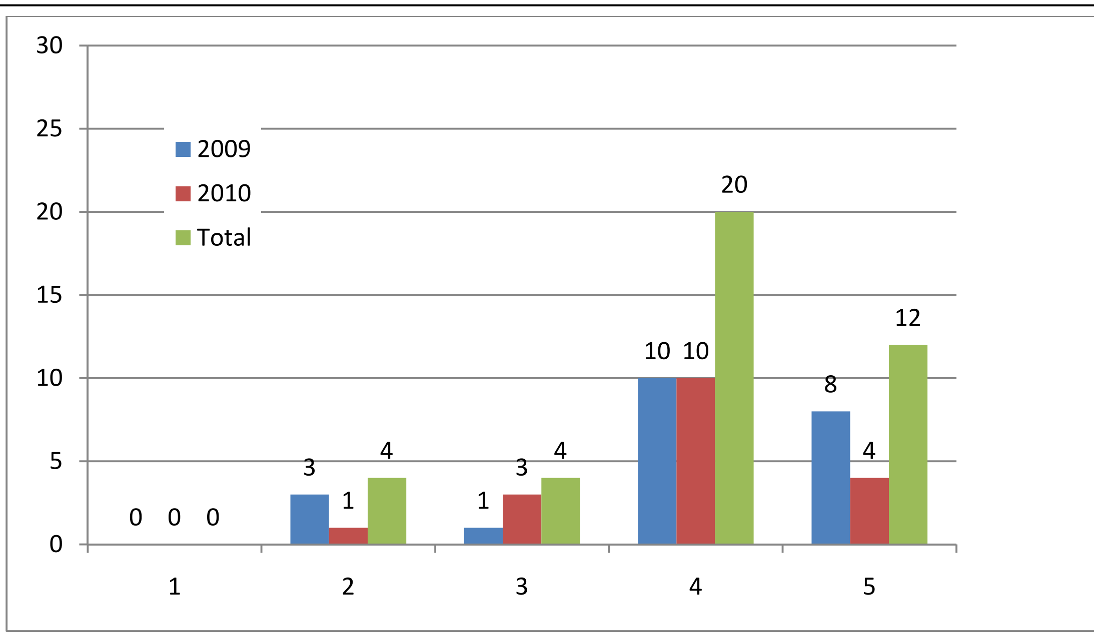

Figure 8: Q6 – "Classroom discussion(s) of this cases study helped me understand the specific course topics"

Appendix A – Survey Questions

1. The specific course topics that this case study was designed to help me understand was as follows:

____

____

2. This case study was an engaging application of these specific course topics.

❒ Strongly Disagree ❒ Disagree ❒ No Opinion ❒ Agree ❒ Strongly Agree

Why?

____

____

3. This case study improved my appreciation of the relevance of these specific course topics.

❒ Strongly Disagree ❒ Disagree ❒ No Opinion ❒ Agree ❒ Strongly Agree

Why?

____

____

4. This case study helped me understand these specific course topics.

❒ Strongly Disagree ❒ Disagree ❒ No Opinion ❒ Agree ❒ Strongly Agree

Why?

____

____

5. Small group discussion(s) of the case helped me understand these specific course topics.

❒ Strongly Disagree ❒ Disagree ❒ No Opinion ❒ Agree ❒ Strongly Agree

Why?

____

____

6. Classroom discussion(s) of this case study helped me understand these specific course topics.

❐ Strongly Disagree	❐ Disagree	❐ No Opinion	❐ Agree	❐ Strongly Agree

Why?

7. What aspects of the case study, and its activities, did you especially like in terms of helping you understand these specific course topics?

Why?

8. What aspects of the case study, and its activities, did you especially dislike in terms of helping you understand these specific course topics?

Why?

9. What suggestions do you have for improving this case study, and its activities, in terms of helping you understand these specific course topics?

10. What are the advantages of using this case study, and its activities, over traditional lectures, in terms of helping you understand these specific course topics?

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