# WHAT DID I REALLY LEARN IN MY MECHATRONICS CLASS ? THE CHALLENGE LINE PROBLEM REVISITED

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## ABSTRACT

Experience gained from a course in Mechatronics Engineering is used to illustrate an approach to the Challenge Line Problem, a problem that is a key pedagogical issue underlying most engineering courses. The issue is how to define and subsequently position an engineering problem between one extreme of a highly constrained, clearly defined problem, and the opposite extreme of an open ended problem with multiple, or perhaps nonexistent, solutions. After several years of experience, it is believed that a course has been established that uses a process of active learning as it moves in stages from being highly constrained to being open ended. This progression along the Challenge Line works to provide the students with a rewarding and stimulating experience in engineering problem solving, in the context of a course that combines elements of computer, electrical and mechanical engineering.

## KEYWORDS

Mechatronics engineering, active learning, problem solving, team project, course design

## INTRODUCTION

The Challenge Line Problem is a name coined by the authors to highlight a pedagogical issue that underlies most engineering courses [1]. The issue is how to provide students with the most appropriate instructional challenges chosen from a continuum of possible problems ranging between two extremes. At one extreme students are provided with highly constrained problems in which there is a clearly defined solution. The other extreme provides students with open ended problems that have multiple potential solutions and includes the possibility that there is no viable solution. An illustration of the Challenge Line is given as Figure 1.

The course, which is the subject of this paper, is laboratory-based and technology-oriented course in Mechatronics Engineering, where mechatronics is the subject that combines elements of computer, electrical and mechanical engineering. The Challenge Line, however, is an issue that underlies most engineering courses. The broad pedagogical issue is how to achieve the optimum balance between narrowly defined problems and open ended problems. In the context of a mechatronics course, questions that must be addressed include what technology to use, what support to provide, what problems to set and how to evaluate student performance. This issue of the Challenge Line is closely tied to that of active learning in engineering education.

Active Learning is said to be the true key to education. Goff paraphrased Piaget and said "… in order for a student to understand something, she must construct it herself, she must re-invent it." [2]. He went on to observe that students who are engaged in the learning process master the material. Students who are not engaged generally do not succeed. The best way to engage students is to create an exciting active learning environment. Active learning is a key element in the conceive, design, implement and operate approach of CDIO to engineering education [3].

In engineering, it has long been recognized that a hands-on project-based or laboratory-based course lends itself naturally to the creation of an active learning environment, be it at the undergraduate [4] or graduate level [5]. Experience with the Queen's course in mechatronics has amply demonstrated the drawback to the laboratory or project-based approach; that is the problem of resources and time [6]. Such courses need specialized physical resources and can consume excessive amounts of both student and instructor time. The Challenge Line problem is also apparent in the amount of student time invested in problem solving, which in turn impacts on the level of frustration that a student (and instructor) can experience in self-directed tasks. Again, the issue is finding the balance between two extremes.

In the context of a robot-based mechatronics course, one extreme is to provide students with a ready made robot which does exactly what is expected when it is turned on. The other extreme requires the students to obtain the electronic parts, assemble the sensor array, program, test, revise and determine if the robot will perform the assigned task within the given constraints. After several years of experience, it is believed that a course has been established that moves in stages from the highly constrained to the open ended region of the Challenge Line. The course also serves to provide students with a rewarding and stimulating experience in engineering

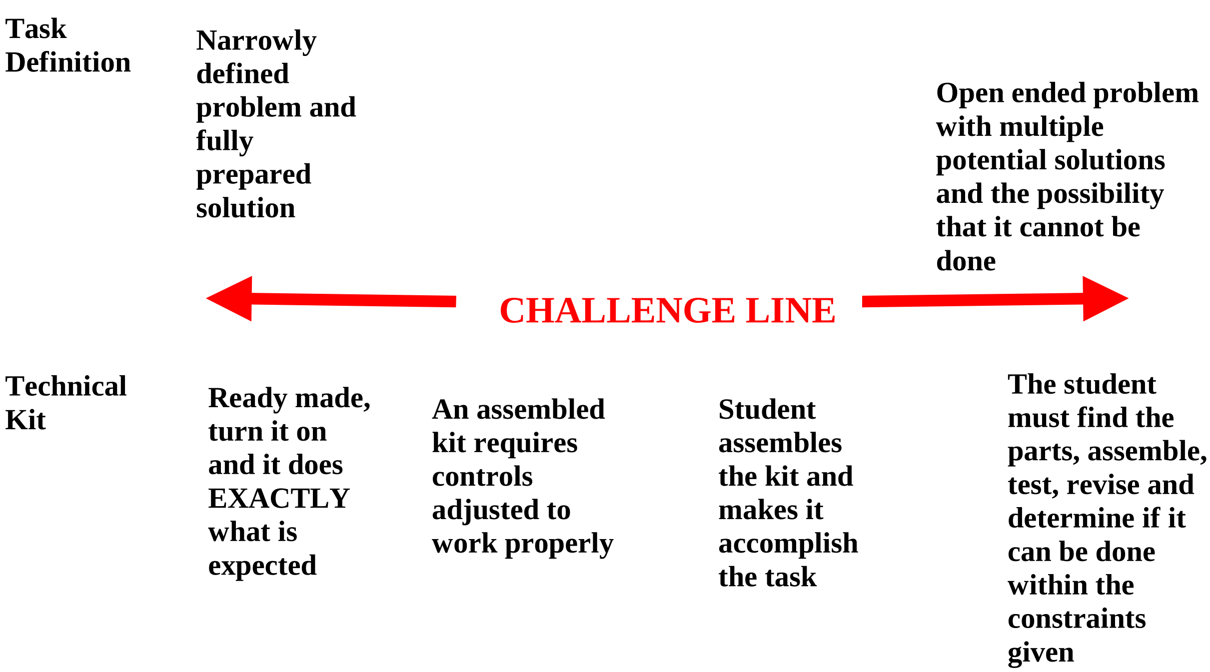


Figure 1. Challenge Line with constrained problems on the left and open ended on the right

problem solving, within a process of active learning. It does so through a combination of lectures, tutorials and laboratories that culminates in a team project which requires the students to assemble and program a team of robots to perform a given cooperative task.

## AN APPROACH TO MECHATRONICS

The Queen's approach to mechatronics is to focus on the application of electronics and microcontrollers to mechanical systems. The course is designed around a series of tasks that involve a prototyping board with a microcontroller and a mobile robot that uses the same microcontroller, as illustrated in Figure 2 and Figure 3, respectively. The "MechBOT" mobile robot has a flexible platform on which sensors, actuators and supporting electronic circuits are mounted. The chassis is a commercial R/C controlled four wheel drive ATV mobile robot. It was chosen in part due to the large deck space available to accommodate all of the sensors, actuators and supporting electronic circuits used in the course.

It is acknowledged that just as mechatronics courses are commonly laboratory-based, the mobile robot has been effectively adopted as a standard educational tool [7]. Although mobile robots have regularly been used as a tool in electrical engineering programs, mechatronics has provided an opportunity to introduce such devices to non-electrical, and in particular, mechanical engineering students [8].

A series of eight laboratories is used to introduce the students to the technology, alternating between the application of the technology to the prototyping board in one week, and then the application to the mobile robot in the following week:

- Lab #1 (Introduction to the Stamp microcontroller and the protoboard) and Lab #2 (Introduction to the PBASIC language)
- Lab #3 (Introduction to Sensors, photoresistor mounted on a servomotor) and Lab #4 (Introduction to the Robot, with navigation by contact sensing or limit switches)
- Lab #5 and #6, navigation by ranging (infrared sensor), with Lab #5 as the protoboard based laboratory illustrated in Figure 2, and Lab #6 as the robot based laboratory illustrated in Figure 4
- Lab #7 and Lab #8, navigation by colour (CMUcam camera for colour tracking)

The laboratories are conventional in that they are structured. A handout details the procedure and every group deals with the same hardware. Variation between groups comes about due to the software programming and in the placement of the sensors and actuators. The laboratories could be viewed as one part applied electronics, and one part introductory microcontrollers, with a mobile robot as the application.

For the laboratories, students work in pairs and this occupies the first eight weeks of the course. In the final four weeks of the course, the experience and knowledge gained in the laboratories is applied to a team project. The current version of the project, as illustrated in Figure 5, is posed as a problem that mimics the task of autonomous vehicle navigation, with 2 robots per team traversing the test arena in a cooperative fashion. The test arena has a raised platform from which the robots can fall. Specifically, a team of 2 robots (4 students) is tasked to travel around the loop without hitting any walls (or each other). Red and green balls mimic traffic signals. A colour camera on each robot is used to determine whether the signal is red or green (or yellow). A discussion of the current project as it relates to its competitive aspect can be found in [9].

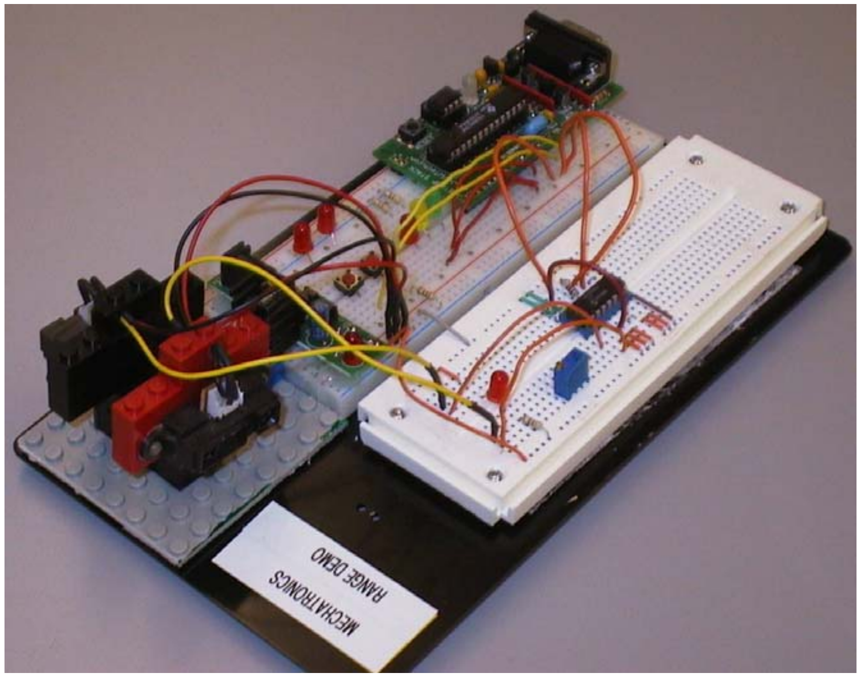


Figure 2. Navigation by range, protoboard based laboratory

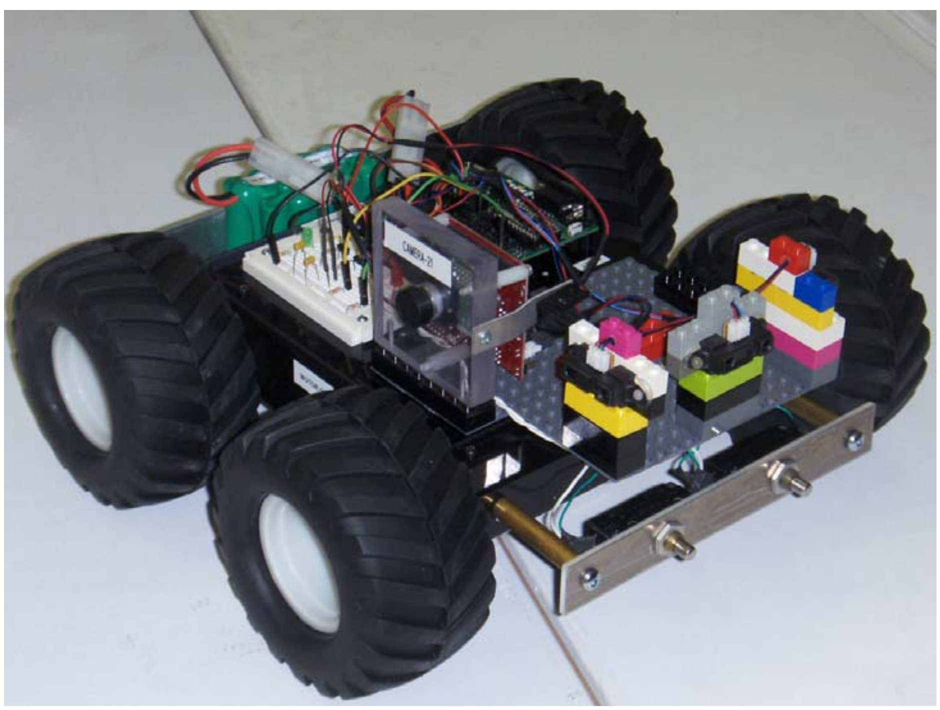

Figure 3.  Typical mobile robot configuration for the team project

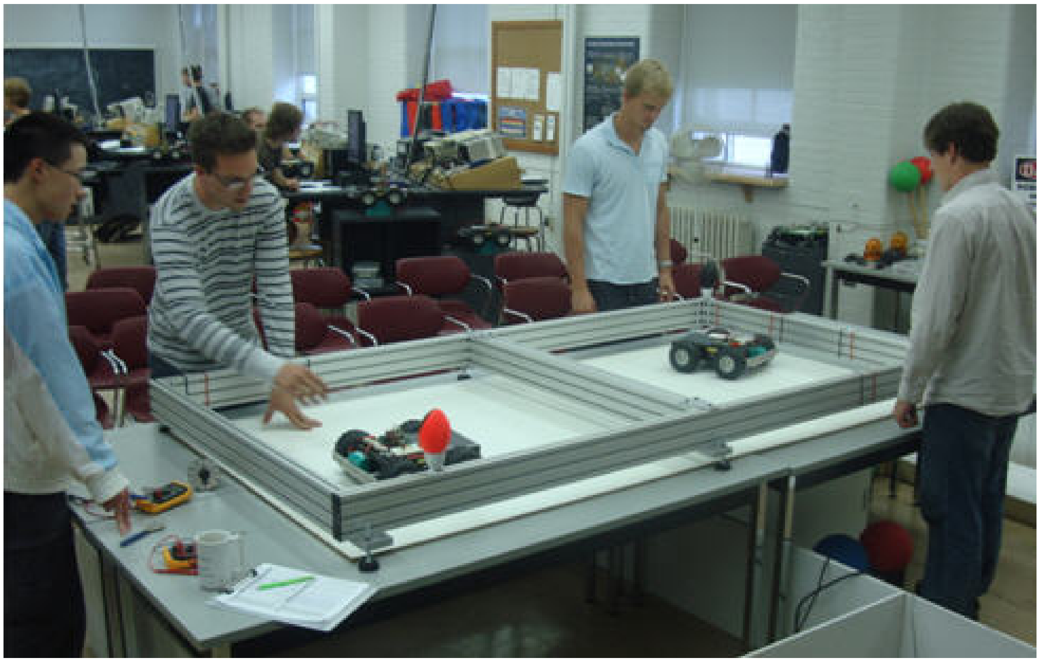

Figure 4. Navigation by range, robot based laboratory

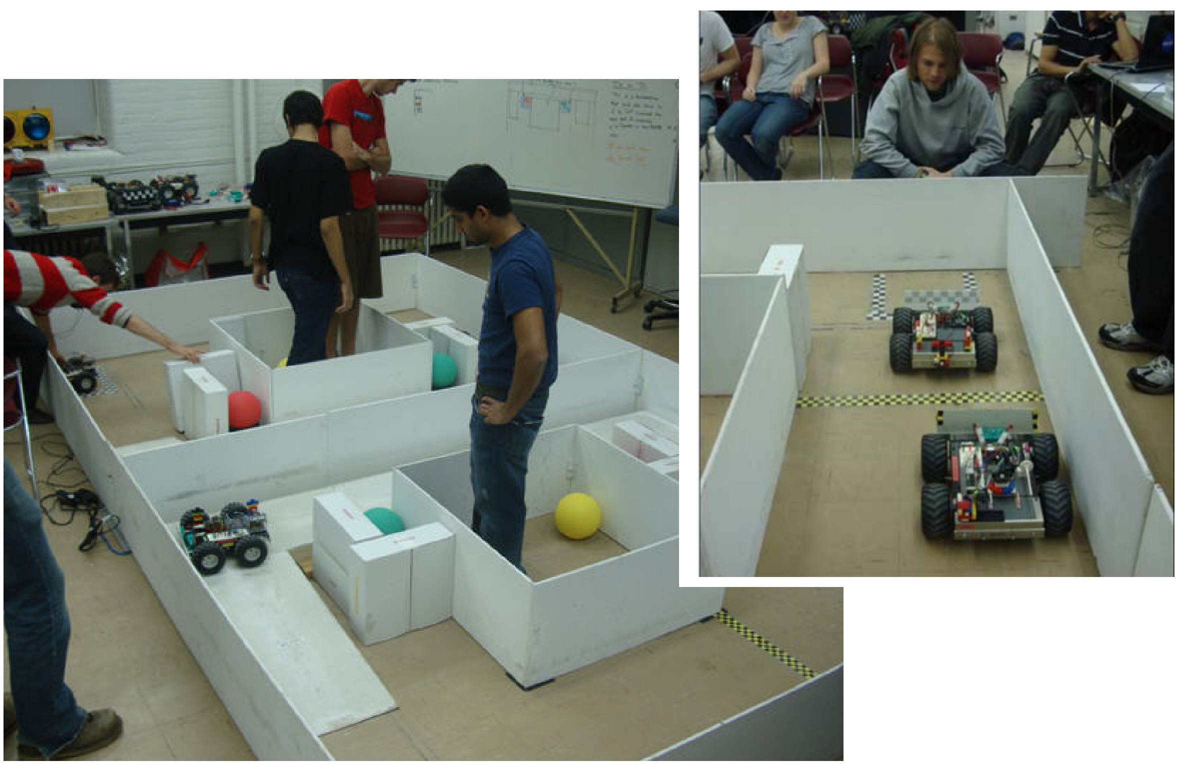

Figure 5. Test arena for the team project (with robots in following mode shown as inset)

## IMPLICATIONS FOR THE CHALLENGE LINE

In reference to Figure 1, it is important to repeat the observation that the course progresses left to right along the Challenge Line, from the structured small group laboratories (same procedure and hardware, but different software solutions are possible) in the first eight weeks to the unstructured team project (with multiple and creative hardware *and* software solutions). The laboratories are carefully organized to introduce the technology needed in the team project as well as to expose the students to implementation problems with individual elements. This reduces the frustration factor when it comes to the systems integration problem presented by the team project. The frustration factor is also minimized by introducing new sensor technology at the protoboard level (for example Figure 2) before applying the technology at the level of the mobile robot (for example Figure 4). Student interest can be used to offset student frustration. Table 1 summarizes this alternate interpretation of the Challenge Line.

## ORGANIZATIONAL DETAILS

The active learning component attracts a group of students that is enthusiastic about the hands-on nature of the course. However, this enthusiasm can become a problem when the hours spent testing and troubleshooting begin to use up time required for other courses. Furthermore, students have 24 hour access to the laboratory so they could work on their projects at any time. Steps that can be taken toward achieving a sensible balance between independent study and limiting the hours spent on the course are as follows:

1. A tight coupling between lecture and laboratory activity.
2. Arranging a preliminary task that is to be completed in the tutorial in order to avoid time wasted in cases where basic errors are being made at the outset.
3. Solid support during the tutorial and the laboratories by people who know the problems and how to solve them.
4. Back up robots and sensor sets.
5. Attendance at laboratories and tutorials is mandatory.
6. Prototyping boards and robots that are prebuilt for the first day with the basic components laid out in the same manner on every robot; troubleshooting is easier and things work quickly in the first laboratory.

Table 1
Variation in student interest level along the Challenge Line

| Left End – Recipe | Somewhere in the Middle | Right End – Open ended |
|---|---|---|
| Following a recipe can be boring. Senior year students in particular are looking for more than a “fill in the blanks lab”.<br>For the first task, starting at the left end of the challenge line helps students to become familiar with the hardware, and software. | The task offers enough new material and student input into the hardware and/or software. The interest generated pulls students into the problem solving process.<br>Students are asking questions, making mistakes and fixing them.<br>The optimal challenge level is indicated when many of the groups are successful or mostly so, and there is clapping and cheering when the task is completed.<br>As students gain experience the tasks move from the left to the right along the challenge line. | Some groups will be frustrated to the point of giving up before solving the task.<br>Some students may perceive the task as unfair.<br>Too much time may be spent on this task in this course.<br>Some students are looking for this type of challenge but their other courses may suffer if the curriculum is not designed to take the workload into account. |

7. Start with prepared sample code for the first task.
8. Have the class gather around the test area and demonstrate successful example runs at the ***beginning*** of the laboratory (except in the final team project) as a method of being clear about the performance assessment criteria, generating relevant questions right away, and giving the students confidence that the task can be done.
9. Provide component data sheets as hardcopy in the laboratory and on course website.
10. Provide a clear handout with the task and the marking scheme clearly identified.
11. Package the material as one week, or later as two week sessions that include a tutorial and a demonstration prior to the actual laboratory.
12. Walk around from group to group during laboratories to keep in touch with progress and do not let a group spend excessive time on a simple troubleshooting problem.
13. Have a large whiteboard on hand and post common problems and answers to common questions as they arise during the course of the laboratory.

Ideally these steps lead to a balance where students are free to work hard at solving problems on their own, yet will not go overboard such that hours in the laboratory detract from the rest of their course work. The importance of Point 8 (prelab demos) cannot be overstated. This is key not only for the actual demonstration, but it also serves as a planning tool. Only by actually doing the task with the tools at hand can an instructor prepare the appropriate instructions and be aware of most (or at least some) of the problems the students will face.

## STUDENT FEEDBACK

Student comments about the course have been universally positive, a selection of which are given below:

- "it's the best class I've ever taken, I like the practical application of things"
- "this course is awesome, I (think) everyone loves it"
- "I liked the hands-on experience, it made learning material easier and more fun"
- "good setup learning how to use components first (alone) and then on the robot"

For the past 5 years, the course has been consistently ranked 1st out of the 12 technical electives offered by the Department, as measured by the University Survey of Student Assessment of Teaching, a formal course evaluation that is conducted for all courses by the university. The course consistently scores 4.8 or higher on a scale of 5 in response to the question "overall, this is an excellent course", with the Department mean at 3.7 (standard deviation of 0.36), where 5 = "strongly agree".

This is not to say that students are uniformly happy with the nature of the course. The fact that assessment is based to a degree on the performance of a robot (that the students have admittedly configured and programmed) leads to inevitable “real-world” frustration, when what worked perfectly in pre-testing, fails in final testing due to unanticipated hardware failures or software bugs.

## WHAT WAS REALLY LEARNED IN THE COURSE

In the last offering of the course the students were asked: "*Name three positive things that you've learned in the class that you think will be of value to you in your future career as an engineer.*" The results were always positive, but rarely mechatronics specific. Students offered comments such as "Teamwork is more important than technical ability" and "You need to be methodical in the problem solving process". The fact that the feedback was positive was not surprising given course surveys from previous years. But the "non-mechatronics" feedback caught the attention of the instructors. On reflection, the exercise highlighted to the instructors that they had designed the course around the process of engineering problem solving, and this has become one of the dominant features of the course. That process in the context of MECH 452 is illustrated in Figure 6 (left side). It compares well to the established Dartmouth/Thayer approach to engineering problem solving that also given in Figure 6 (right side).

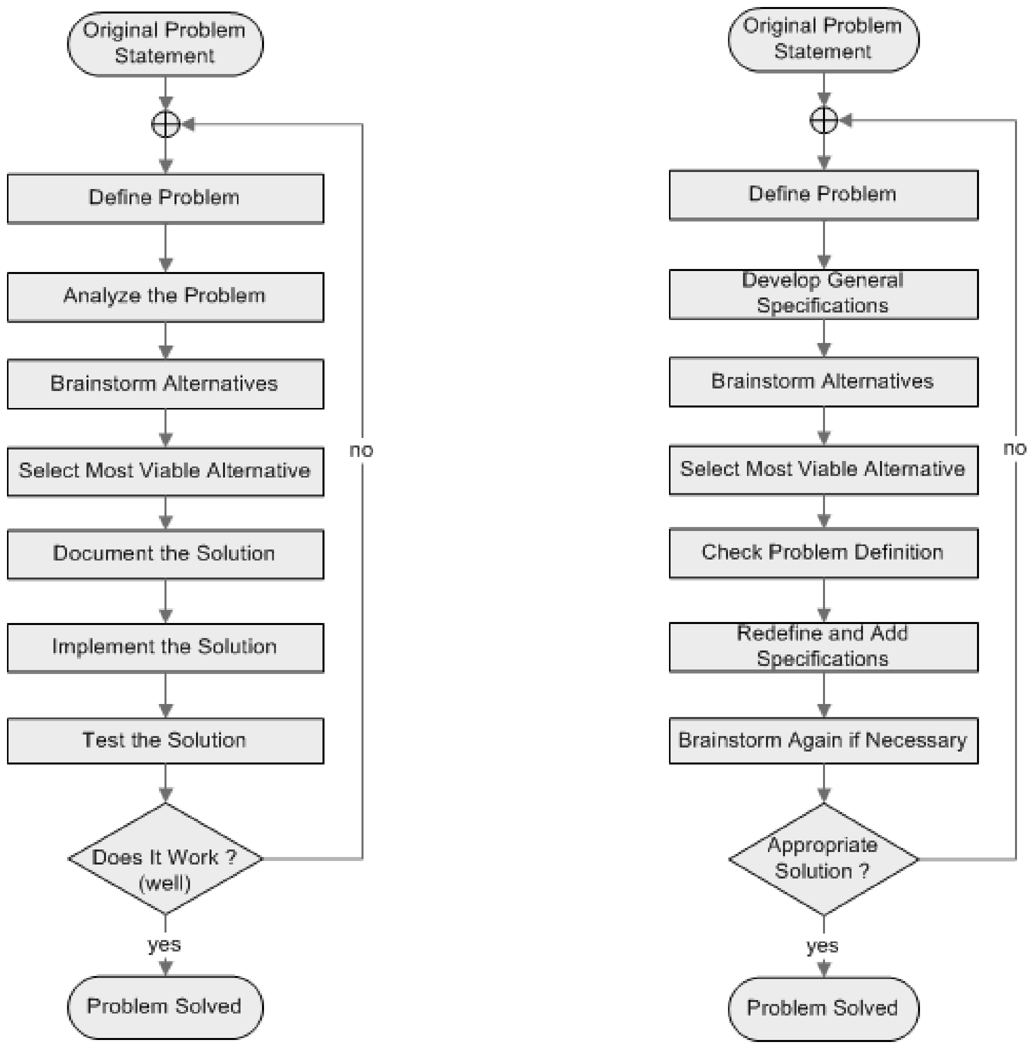


Figure 6. Problem solving in MECH 452 (on left) compared with Dartmouth/Thayer (on right).

The Dartmouth/Thayer approach is put forward as a framework for bringing problems of the "real world" into the classroom [10]. Students solve these problems by proceeding through a problem-solving cycle, step by carefully documented step. If they discover that the solution they are working on is in fact unviable, they are taught to examine their paper trail and move back only so far as they need. In a word, they are taught to proceed methodically and systematically.

Experience has shown that problems must be presented such that the students are "forced" to be methodical. The team project problem is broken into 3 parts, roughly 1 part per week. Each part is broken into 3 tasks:

> ***Demo Task***: Contains basic elements of the overall task. Students must demonstrate successful completion of the Demo Task (pass/fail mark), before being permitted to continue with the Basic Task. Students who fail this task are permitted to repeat this part of the project for part marks in the final week of classes ("supplementals week").
>
> ***Basic Task***: Contains all but one of the elements of the Advanced Task, with the mark based upon the best of 3 trails.
>
> ***Advanced Task:*** Same as Basic Task with one additional element, and only one trial.

This approach was found necessary to "force" students to break the task into manageable parts, as well as to find a compromise between the academic nature of the exercise and the real world nature of the task, where the mark was based directly upon the performance of a machine, and only indirectly on the performance of the student.

## CONCLUSION

After several years of experience, it is believed that a mechatronics course has been established that moves in stages from the highly constrained extreme to the open ended extreme of the Challenge Line and provides the students with a rewarding and stimulating experience in engineering problem solving, within a process of active learning. It does so through a combination of lectures, tutorials and laboratories that culminates in a team project that requires a team of students to assemble and program a team of mobile robots.

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Kevin Firth is currently building CNC glass cutting and laser etching machines for use by his company, ASK Science Products Inc. (Kingston). In the field of education he is involved in teaching with mechatronic platforms at the university and secondary school levels. He has been involved with the Queen's Mechatronics Engineering course since 2000.

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