Teaching problem solving skills to radiation protection students

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Abstract
Problem solving skills are essential for all engineers and scientists. Although some students have more natural problem solving skills than others, all students require practice to become comfortable using these skills. At the University of Ontario Institute of Technology a course was developed as part of the core curriculum to teach students problem solving skills, along with elements of modelling and simulation. The underlying emphasis of the course was to allow students to develop their own problem solving strategies, both individually and in groups. Direction was given on how to examine problems from different perspectives, and how to determine the proper root problem statement. Computational aspects of problem solving are explored in the course using the commercially available MATLAB computer code. A number of case studies were presented as both example and problems to the student. Emphasis was placed on solutions to problems of interest to nuclear engineers and radiation scientists. This paper describes the methodology and tools used at Canada's newest laptop-based university to teach the next generation of nuclear engineering and radiation science students essential problem solving skills.

1. Introduction

The mission of the University of Ontario Institute of Technology [1] is to be a market-driven university. The vision statement of the University is stated as follows:

> *"The University of Ontario Institute of Technology will be a market-driven University, integrating inquiry, discovery and application - through excellence in teaching and learning, value-added research and vibrant student life."*

One of the implications of both the mission and the vision of the University is that students should be prepared to immediately enter the work force should they choose, without additional training. Therefore, students must acquire skills during their University education that are often only fully developed when they reach the workforce or after graduate school.

When developing the curriculum for radiation protection and health physics options at UOIT [2], much effort was placed by the program advisory committee on developing courses that would allow students to be immediately useful to industry upon graduation. One area that was identified by the majority of the committee as being a useful course early in the radiation protection program was problem solving. In addition, the faculty believed it was important for students to obtain experience in numerical problem solving techniques and simple simulation. Therefore, a course that encompassed the concepts of problem solving, plus modeling and simulation was developed for first semester of the second year of the program. This hybrid course incorporates elements of conceptual problem solving, with case studies derived from high risk, high consequence situations. In addition, numerical examples from engineering and radiation protection were used to emphasize key concepts. The course was designed as a two hour per week lecture, plus a 2 hour per week tutorial. The tutorial in this course was used exclusively for teaching MATLAB [3], and practicing numerical problem solving.

This paper discusses the problem solving, modeling and simulation course developed at UOIT, and the results as measured by qualitative feedback received from students.

2. Identifying the traits of effective problem solvers

The problem solving aspects of the course begin with an introduction of desirable traits for effective problem solvers. The course briefly introduces the concepts of metacognition ("thinking about thinking") and challenges the students to be aware of how they think, and how they solve problems that are around them everyday. Conclusions from Steven Covey's book "The 7 Habits of Highly Effective People" [4] are introduced to demonstrate areas that have been shown to be common to effective problem solvers. The seven habits: (1) being proactive, (2) beginning with the end in mind, (3) prioritizing, (4) thinking positive, (5) communications, (6) synergism and (7) life balance are each presented and discussed with the student. Traits such as risk taking and paradigm paralysis/pioneering are also discussed in the course.

3. Developing the problem solving heuristic

A heuristic is presented for the students to follow. Although there are a great many ways to approach problem solving, the heuristic is generic and universally broad. The heuristic adopted is a five point strategy, which involves (1) defining the problem, (2) generating solutions to the problem, (3) deciding upon a course of action, (4) implementing a chosen solution and (5) evaluating the effectiveness of the solution.

Problem definition is developed into an eight step process that includes harvesting information, talking with people familiar with the problem, viewing the problem first hand, confirming findings, determination if problem should be solved, gathering data, forming hypotheses and brainstorming problem causes and solutions (which is really the first step to generating solutions). Problem definition is performed qualitatively through present state-desired state analysis, problem statement and re-statement and Dunker diagrams.

Solution generation is introduced by examining mental blocks and blockbusting. The actual generation of solutions are developed into three broad categories of brainstorming, cross-fertilization and incubation. The brainstorming technique is presented as a graphical construct that can be performed using a cause and effect, or fishbone, diagram.

Deciding upon a course of action in the problem solving course is presented using a combination of Kepner-Tregoe (KT) analysis [5] and the Six Thinking Hats [6] approach. KT analysis involves many semi-quantitative results using situation analysis, Pareto analysis, problem analysis, decision analysis and potential problem analysis. Decision analysis includes tools familiar to the nuclear industry, such as failure modes and effects analysis, fault and event tree analysis and cost benefit analysis.

Implementation of the solution decided upon involves discussions of four implementation phases: (1) approval, (2) planning, (3) carry through, and (4) follow up. Implementation also leads into discussion of modeling and simulation. The final step of the heuristic is evaluation of the solution and includes topics such as ethics and safety. The course finishes by putting together all elements of the heuristic and applying them to some case studies. A summary diagram of the elements of the heuristic is presented in Figure 1.

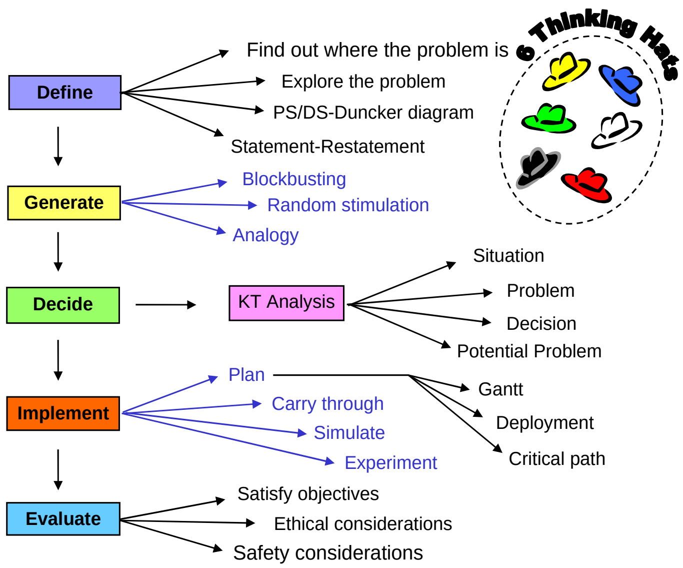

Figure 1 - Elements of the problem solving heuristic

4. Case studies

A number of case studies were used to emphasise key points in the course, and to explore the heuristic process. Some case studies were set up in generic parable form, where others were extracted from identified real-world events. Table 1 presents some of the case studies used in the course and some of the key concepts that were explored.

Case Studied	**Key concepts**
Eastern Airlines L-1011 Crash in the Everglades	Demonstrate the consequences possible when the root cause of the problem is not solved.
Flixborough, England Cyclohexane Explosion	Demonstrate the consequence of posing an incorrect solution to a correctly stated problem.
Exxon-Valdez Oil Spill	Discuss the common modes of failure in complex systems.
Pontiac Aztek Poor Sales Performance	Demonstrate problems with communication in problem definitions.
Aircraft crash statistics	Used to generate and explore Pareto analysis
Buffon's needle problem	Simple Monte Carlo simulation
CANDU steam generator scaling	Gantt charts, deployment charts and critical path analysis
Charles Joseph Minard map: *Napoleon's March to Moscow*	Graphing and display of quantitative information

Table 1 - Case studies based upon real events used in the problem solving course

Case studies are extremely important to bind the often abstract problem solving heuristical concepts with real-world problems, and to generate student interest in the material.

5. Modeling, computational problem solving and simulation

Throughout the problem solving course, students are learning increasingly advanced computational concepts through the use of the MATLAB™ code, and are simultaneously learning topics related to their degree program, specifically in nuclear physics. It is therefore extremely desirable to introduce the students to solving problems related to radiation protection and nuclear engineering using both hand calculations and the MATLAB code. MATLAB (MATrix LABoratory) is a high level programming environment for performing complex array-based computations. In addition to its computational abilities, it also provides immediate interactive plotting capability, and the ability to generate graphical user interfaces.

As previously discussed, MATLAB was taught during tutorial sessions to students, and assumed no prior programming knowledge. Concepts covered included (i) array operations, (ii) creating functions, (iii) logical operators, (iv) loops, (v) advanced plotting, (vi) interpolation and regression, (vii) solving linear systems of equations, (viii) simple probability and statistics, and (ix) numerical differentiation and integration.

A number of radiation and nuclear science topics are presented throughout the course as appropriate. The individual topics may differ between yearly offerings of the course. Some numerical examples used in the past include energy release from alpha decay of U-235, age of the Earth using isotopic abundances, nuclear binding energy (first principles and Weizsäcker binding energy formula), U-235 thermal cross section processing and iodine/xenon build-up and decay in a nuclear fuel. Students were introduced to numerical methods such as finite difference approximations, forward, backward and difference methods for solving PDEs, and basic Taylor series expansions.

Students are introduced to modeling and simulation of nuclear processes. They are taught some of the characteristics of modeling health physics and reactor physics problems. They are also taught about stochastic simulations using Buffon's needle problem to calculate the value of pi, which subsequently leads into discussions of Monte Carlo analysis, and with simple Monte Carlo solutions to the Boltzmann transport equation. Students are also provided instruction from nuclear plant simulator staff, who bring in real-world nuclear simulator expertise.

6. Group project

One important aspect of the problem solving course is the assignment of a group project. Students are informed early in the semester that a group project is required, and that they must self organize into groups no smaller than 4 and no larger than 6 students. The groups are then given a topic which is related to their field (for example, the Pickering Nuclear Generating Station Unit A loss of coolant accident in 1983) and are given the scenario and a number of analysis objectives. The groups are asked to use their organisational and problem solving skills to provide a number of deliverables. For the case of the Pickering accident, groups were asked to provide the following:

General Documentation

1. Description of the Pickering A NGS, its relationship to other CANDU reactors in Canada, and its importance to power generation in Canada
2. Description of the accident, including LOCA event sequence (timeline)
3. Media pack (brief plant description & media release)
4. Statement to employees
5. Goodwill flyer (statement to neighbours)

Technical Analysis

6. Situation analysis at the time of the event (analyze the operator's situation at time of failure)
7. Analysis of the problem(s) producing the fault (problem analysis)
8. Analysis of how the operators corrected the fault (decision analysis) and comment
9. Analysis of how to prevent future faults (potential problem analysis)

Management

10. Project management chart (Gantt chart) outlining a strategy for inspecting all of the pressure tubes at the Pickering station (units 1 through 8)

Students are expected to utilise the skills they have learned in class, for example Duncker and Fishbone diagrams, Pareto charts and KT analysis. The students are also required to produce Microsoft Visio™ and Microsoft Project™ charts and graphs. However, they are not formally taught these tools in any UOIT course. They are therefore instructed that this is a problem based learning (PBL) exercise, with one of the objectives to be to "teach to" and "learn from" other group members.

7. Observed results

Student reviews of this course were overwhelmingly positive. Numerous students would meet with me and describe how the concepts they had learned, such as root cause analysis and incubation, really do work in their lives. Students also took great pride in their group projects, and many used them as examples of teamwork when applying for industry internship positions. Most students continue to utilize MATLAB for assignments, laboratories and research papers in other courses, and also use the computational theories and algorithms that were developed.

The melding together of soft-science problem solving philosophies with hard-science radiation oriented problems allowed students to see how the methodologies could be applied in their careers, which I believe assisted in them accepting the concepts. Case studies helped to emphasise key points, and make the material more interesting.

It is uncertain whether problem solving, modeling and simulation was the students' most important course in first semester of second year, but I am convinced that it was essential for laying the foundation required to enter the workforce directly as a radiation protection professional.

References

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