Thinking like an engineer: "guest listener" contributions to a problem-based learning course

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***Abstract**: The process of thinking like an engineer was explored in a problem-based learning course in environmental engineering. Guest engineers were invited to participate in workshop based around dialogue between students and the guest engineer. Questions and comments by the guest engineers in each of three weeks were collated and classified. Scope of the project, specific technical points, sources of information, approach to the project, capability of participants and overview of the purpose of the project were found to be an evident classification of the questions and comments made by guest engineers. Explicit discussion of the thinking processes revealed by the dialogue followed the workshop. Students remained engaged in the dialogue as they were simultaneously receiving relevant advice and information related to their projects.*

Introduction

Engineering thinking has been recognised as an area requiring future educational research (Radcliffe, 2006). In contrast, the study of scientific thinking has a much longer history (Williams et al., 2004). Ahmed et al. (2000) showed that the study of the question-and-answer discourse between experienced and novice design engineers provided insight into how engineering thinking skills are transferred.

Smythe (2004) observed that educators often conceal the process of thinking behind their teaching whereas, "there is a need to strive to make the experience of 'thinking' more public." To allow students to observe such "public" engineering thinking, "guest listeners" (instead of guest speakers) were invited to attend workshop classes in a problem-based learning course. The guests were engineers who were asked to listen to the students outlining their projects and then respond from their experience as engineers. The intention was for students to gain not only practical advice on their projects but a window into how engineers think when confronted with unfamiliar or unclear problems.

Community Projects 1 class workshops

Integrated Community/School Projects 1 is a new course in the renewed Bachelor of Engineering (Environmental) program in RMIT University, School of Civil, Environmental and Chemical Engineering. It is a core course in the second year of the program and is followed by Community Projects 2 in year three. The aim of the course is to develop students' ability to work in teams and negotiate project outcomes with a community group. The projects have the complexity and ambiguity that comes with real world problems (Jonassen et al., 2006).

During the semester, class workshops address essential skills. In each of weeks 3 to 5 an engineer was invited to attend the workshop without any prior briefing on the projects. After a brief introduction from each team on their project, and a brief introduction from the engineer about their area of practice the guest engineer was asked questions by the students. All participants were aware of the dual aims of this workshop being, 1) to assist the students make progress in their projects and 2) for guest engineers to model "thinking like an engineer". The course coordinator (author of this paper) was only involved in opening and closing the discussion and taking minutes. In total over 125 questions/comments by the guest engineers were recorded. The data are presented (in the Appendix) and analysed here to investigate what they may demonstrate about the process of thinking like an engineer.

Classification

The questions and comments made by the guest engineer were recorded during the discussion. The questions or comments were counted separately when they addressed a different topic or were responded to by students. There are many possible ways to consider classifying the comments. The emphasis sought in this analysis was the way the guest engineers contributions to the discussion focussed on the projects. The first group of comments that were apparent were those addressing the scope of the project. These included questions e.g. "What's the problem?" (E2P3) and statements "You need to consider the impact of irrigation." (E3P1). Another grouping of comments was those relating to identifying sources of information that may be available. Other comments related to approaches on how the project aims were or could be addressed. Some comments were of a specific technical nature related to the project. These comments could potentially have been considered in some cases as scoping or source related however it was considered useful to this analysis to differentiate these as a separate group. Some comments related to the capabilities of the student team, the community group and in one case of the guest engineer. These comments were grouped together as relating to capability. Some comments were not specifically related to the project but addressed more general ideas or put the project in a broad context. These were classified as overview comments (Fig. 1).

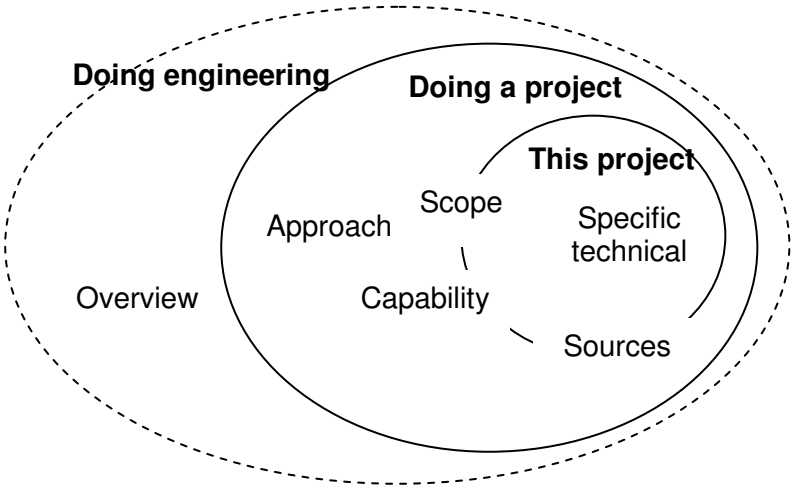

Figure 1. Schematic illustration of the rationale of the classification used for comments.

In summary, the guest listener responses the following classification was made:

1. *Specific technical*: information directly applicable to the aims of the project.
2. *Scope*: identifying boundaries and objectives of the project.
3. *Sources*: identifying where information relevant to the project may be obtained.
4. *Approach*: methods for making progress in the project.
5. *Capability*: ability of student team, community group and guest engineer, relative to project objectives.
6. *Overview*: abstract observations based on the process of the project.

This classification has some similarity to the Project Handbook compiled by staff of the School which includes the following recommended questions for students to ask of themselves in order to make progress in their projects:

- What do we know about this?
- What are some possible solutions or ways forward?
- What do we need to know?
- Where can we find out?
- Who will do the work?

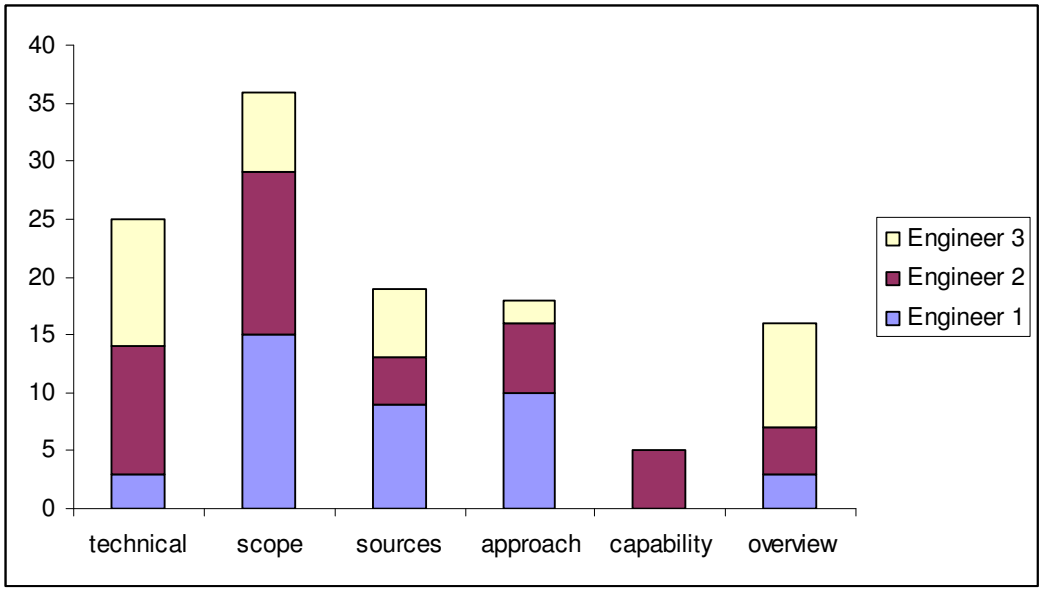

Figure 2. Stacked column graph of the classification of comments. Y-axis is the number of occurrences.

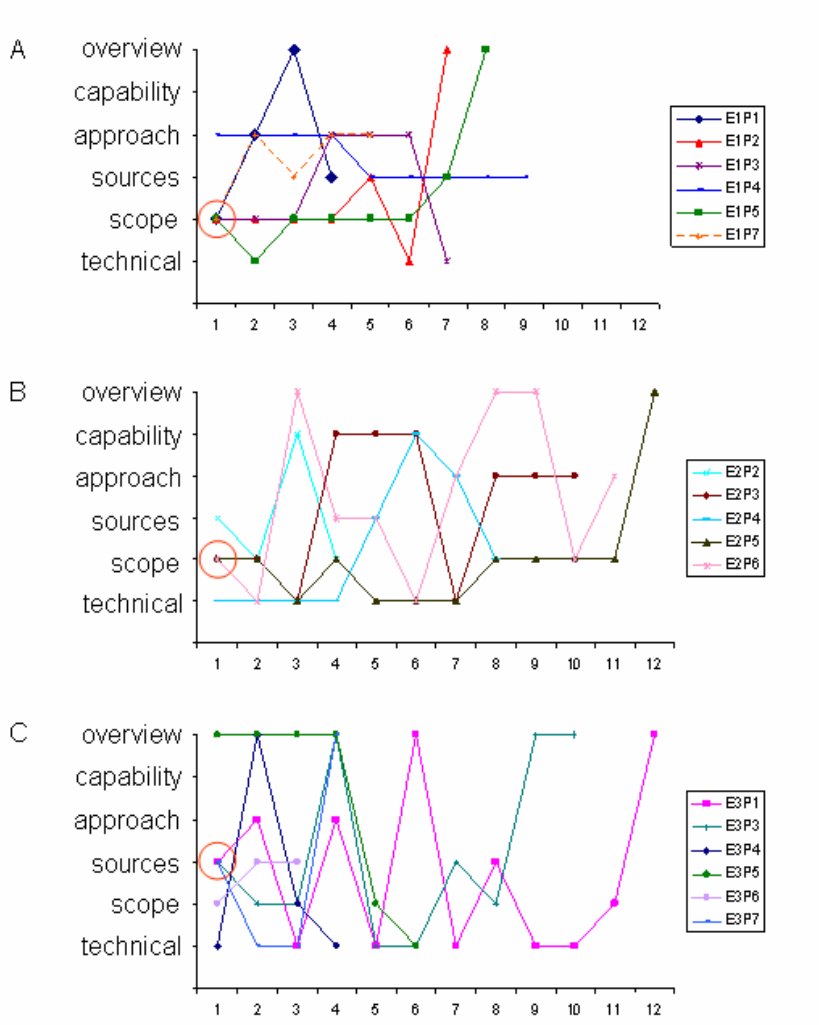

Figure 3. Line graphs showing the classification of comments in the order they were made during discussion (ordinal x-axis) for guest engineers 1-3 (A-C). E1P1 refers to engineer 1 commenting on project 1. Orange circles show the most common first comment.

Results

When classified, the questions and comments (Figure 2) show a range of distribution between topics and between the three engineers. To explore further, the questions and comments for each project are plotted in sequential order of the dialogue for each project (Figure 3). Many of the exchanges commence with questions and comments about scope as the guest engineer clarified the nature of the projects. Each week's discussions varied in that a different engineer was visiting the class to participate in the workshop and also in that the students had made additional progress in their project each week. An interesting observation of Figure 3 is that in the first week of the workshops (Figure 3 A) the engineer makes a number of sequential questions and comments of the same type as illustrated as horizontal segments of the line graph. The third week (Figure 3 C) is distinctive in that there are very few sequential questions and comments of the same type as illustrated by very few horizontal segments of the line graph. This variation may be purely due to different styles of dialogue employed by the visiting engineers. However, it is interesting to note that in the second week (Figure 3 B) there is an intermediate pattern as illustrated by the presence of only some horizontal segments of the line graph. A possible explanation is that as the student's progress in their projects and gain experience in explaining their projects to a visiting engineer the dialogue becomes more dynamic as the visiting engineer makes questions and comments which span a wide range of types as classified.

Conclusions

Inviting engineers to listen to students explain their projects and enter a dialogue can provide a valuable insight into the process of engineering thinking. Making engineering thinking public to the students in this way provides an opportunity for students to learn important thinking skills. For example, attempting to classify questions and comments provides a model for deliberate focussed thinking. Students remained engaged in the activity because they were simultaneously receiving practical advice pertinent to their projects.

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Appendix

1. Regional Landcare Group

Investigate issues related to this group's project on commercial growing of seaweed in saline dams to utilize land affected by groundwater salinity.

Engineer 1

- Everything is possible, it depends on how sold they are on seaweed. Perhaps some group members could look at other options. (scope)
- You define the scope of the work. Next year you can follow on. (approach)
- Has no one thought of growing seaweed? (overview)
- See [staff member] who is a water expert. (sources)

Engineer 2: no discussion

Engineer 3

- You are welcome to come on the salinity fieldtrip. (sources)
- There are many management strategies to move forward with the issue. (approach)
- Soil type plays a role in the capillary rise, e.g. the mythical "2m" capilliary rise. (specific technical)
- Good exercise to find out where to get soil maps. (approach)
- If pumping water out, you're reducing the water table level. (specific technical)
- Who's causing the problem in the time frame? (overview)
- Need to know about rate of movement of groundwater. (specific technical)
- Go to [consulting company] website. (sources)
- Methods used include cropping, sequential plantings. (specific technical)
- Salt harvesting has been done. (specific technical)
- You need to consider the impact of irrigation. (scope)
- Must understand the big picture/total system. (overview)

2. Coastal Environmental Group

Design nesting boxes for penguins. Tricky design specifications: must survive on the breakwater, be camouflaged from the public and be attractive to penguins.

Engineer 1

- What do the boxes look like? (scope)
- Where do the penguins nest now? (scope)
- Why is that not acceptable? (scope)
- What is the population? (scope)
- Have you been to Phillip Island to observe their management plan? (sources)
- Any evidence that the penguins also nest on the beach? (specific technical)
- I'll be interested to see your possible solutions. (overview)

Engineer 2

- [Originator of project] should know what boxes are required. (sources)
- Are they located away from wave action? (scope)
- Do you have manufacturing skills? (capability)
- Do they need to be hidden? (scope)

Engineer 3: no discussion

3. "Friends of" ABC Creek

This project will address weed control and tree planting, "poplars: heritage trees or weeds?", wildlife corridor fragmentation, how to increase community engagement, developing a concept plan, planned by-pass construction.

Engineer 1

- Is there a strategic plan? (scope)
- Is there an options plan? (scope)
- Has the feasibility of options been addressed? (scope)
- Seems to be a lack of options generating. (approach)

- Get the basic information about options written down. (approach)
- Develop a well reasoned plan. (approach)
- Consider the different herbicide treatments and doses. (specific technical)

Engineer 2

- What's the problem? (scope)
- Does the group intend to apply for funding? (scope)
- What funding source for grants? Council endorsement will be needed. (specific technical)
- How serious is the group? (capability)
- Not many resources available for this type of work. (capability)
- Group needs to get serious. (capability)
- Different options: indigenous plants, heritage values. (specific technical)
- Draw up a more detailed plan. (approach)
- Include an engineering hydraulics plan. (approach)
- Listing issues and stakeholders: Council, residents... (approach)

Engineer 3

- Read a report [previous students] did. (sources)
- Is water quality an issue? (scope)
- Does water quality need to be managed? (scope)
- Can't solve one issue and ignore others issues. (overview)
- Island is an asset if protected from predators. (specific technical)
- Does the area contain preferred habitat? (specific technical)
- Dumping basalt blocks looks constructed. Use natural stone? Good coastal examples. E.g. Constructed flat rock platform at Auckland NZ a superb "natural" design. (sources)
- Cost comes in to it. (scope)
- In research work there is a lot beyond the scope of the work that still needs to be considered e.g. water quality. (overview)
- Deeper drilling for rail loop was required because of poor planning. (overview)

4. “Friends of” XYZ Gully

This project will address the need for a land management plan for this small stormwater catchment full of potential. Issues include historic gold mining, industrial discharge, dumping of fill, underground cables, groundwater levels and swamp formation.

Engineer 1

- Your next phase is to define alternative solutions. (approach)
- Get into action but continue researching. (approach)
- Make a boundary around what is achievable. (approach)
- Include breadth and depth in the way you tackle the project. (approach)
- For pollution issues see [staff member]. (sources)
- Is there are stream gauging station nearby? (sources)
- Check Victorian water data web site. (sources)
- Need to approach utility organisations. (sources)
- Find out about utilities and services in the area by contacting ‘dial before you dig’. (sources)

Engineer 2

- Estimate the volume of retention basin, wetland. (specific technical)
- Calculate volume of basin. (specific technical)
- Is there water there now? (specific technical)
- Need to maintain detention basin volume. (specific technical)
- Contact the water and gas companies. (sources)
- [Personally] can't comment on vegetation. (capability)

- Resolve maintenance costs from the start. (approach)
- Need survey plan and drainage plan, but no time for that in this study. (scope)

Engineer 3

- Plant selection is specialised. E.g. in mine rehabilitation not too much reeds in a coal mine are may become a fire risk. (specific technical)
- Erosion, geotextiles, jute fabrics, soil type, soil quality/vegetation; complex holistic thinking is needed. (overview)
- Scrap metal: obvious but least of the problems? What industrial activity has occurred on the site? What contamination may be present? (scope)
- Noxious weeds: they find a niche free of competitors. Natives can succeed, e.g., Hawthorne bush versus leptospermum (tea tree) if there is a level playing field. (specific technical)

5. Metropolitan High School

Design of a sustainable vegetable garden including the recycling of rainwater.

Engineer 1

- What experience do you have in gardening? (scope)
- Raised garden beds also provide good drainage. (specific technical)
- How much water capacity do you need? (scope)
- How many square metres of garden is there? (scope)
- Will you take a range of planting options to the client? (scope)
- Would teachers find it helpful for you to provide information on water requirements – "ballpark" estimates. (scope)
- There is an enormous amount of information out there. (sources)
- For kids to see food growing is important. (overview)

Engineer 2

- Will the garden area be used for outdoor classes. (scope)
- Will the areas be separate? (scope)
- Some technical issues include: raising beds, water from roof harvested. (specific technical)
- Grant application due at end of August. (scope)
- A first flush system may be needed. (specific technical)
- Selection of water tanks requires some calculations. (specific technical)
- Two considerations: pumping versus gravity. (specific technical)
- Is a lock up area needed? (scope)
- Lighting and shadow needs to be considered. (scope)
- Would a greenhouse be part of the design? (scope)
- What about composting of waste from the school cafeteria? (scope)
- It's good to close the loop - eat the vegetables. (overview)

Engineer 3

- Sounds like Jamie Oliver's work, holistic approach, sustainability. (overview)
- Small projects have the same issues that must be addressed in big projects. (overview)
- It will be a useful engineering exercise to cost the filling option. (overview)
- I like the opportunity for the school to promote their sustainability. (overview)
- Consider water quality analysis. (scope)
- If importing soil you need to think about weeds. (specific technical)

6. Metropolitan City Council

Developing an off-leash and dog walking policy for a multi-use public park.

Engineer 1: no discussion

Engineer 2

- It sounds like park management. (scope)
- Problems with pedestrians, options: move bike path, no off lead areas. (specific technical)
- It's a tricky problem. (overview)
- Investigate legal controls. (sources)
- Contact other councils about dogs. (sources)
- Off-lead areas are still only 5-10 yrs old – we're still learning. (specific technical)
- Need to work with a Management Plan and Committee of Stakeholders. (approach)
- Options may favour some stakeholders, disadvantage others. (overview)
- Engineers often work as a project manager: 'here are the issues', objective analysis, consult with other specialists, design some features, use 1st principles. (overview)
- Who is at the community meetings? (scope)
- At a public meeting don't push a solution. (approach)

Engineer 3

- Seems to involve multiple park users with conflicting uses. (scope)
- Use notes from [previous course] including information on community consultation, mining projects, road projects. (sources)
- Get information on park management from Parks Victoria. (sources)

7. Regional Property with Landcare Issues

Landcare to remediate soil instability around a farm dam.

Engineer 1

- Are trees the only solution? (scope)
- A good opportunity to do some serious research. (approach)
- These problems have been around a long time [i.e. prior work is available]. (sources)
- Laboratory testing may be possible. (approach)
- Look for extreme values. (approach)

Engineer 2: no discussion

Engineer 3

- Use aerial photos to make a cross section and determine distribution of landslides in the area. Big picture of what slopes, size, geology recent or old. (sources)
- It may be an inappropriately sited dam, high water table may be maintained for example the back scarp of land slip. (specific technical)
- Could plant trees but have the slip may move again. (specific technical)
- If possible, deal with facts not feelings. (overview)

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