A Procedure for Gathering Experience from Practicing Engineers in order to Teach Experience in the Classroom

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Abstract
Helping students transition from novice to expert requires imparting some level of experience. In order to teach experience in the undergraduate classroom, the instructor must have a record of that experience. For the purposes of this discussion, "experience" and "knowledge" have the same meaning. In some cases, that experience has been recorded in books and journals. Books and journals, however, often focus on low- to mid-level cognitive skills: knowledge, comprehension, application, and analysis. Thus, the experience that forms the basis of high-level cognitive skills, synthesis and evaluation, often exists only in the memories of practicing engineers. Therefore, in order to teach how practicing engineers have transitioned from novice to expert, instructors might need to gather experience directly from the practitioners.

It is important to note that much of the cognitive psychology literature focuses on obtaining information on how experts choose which experience or knowledge to use to make a decision (decision making). That is different from the techniques used to obtain the experiences as data (knowledge). Techniques for obtaining experiences include case study, critical incident, and question-and-answer. Each technique has advantages and limitations which are discussed.

The authors have used all three techniques in interviews with practicing structural engineers to elicit the tools used to evaluate the reasonableness of analysis and design results. Of the techniques, critical incident proved to be the most effective for eliciting this type of information. Interviews with 35 practicing structural engineers resulted in 67 specific incidents of errors discovered. Using the question-and-answer technique with the 35 engineers resulted in just 20 tools for evaluating results. This paper presents a detailed description of how the critical incident technique was implemented along with guidelines for adapting the technique for use by other researchers.

Introduction
An important goal of the education process is to help students in the transition from novice to expert in one or more areas. Beginning with the research of Newell and Simon (1972), a considerable body of knowledge now exists describing how people transition from novice to expert status (Ashcraft, 2006; Solso, 1995). The major type of data used when studying problem solving is the "verbal protocol." The verbal protocols provide a window into the minds of the experts. The verbalizations can then be used to troubleshoot the performance of students as they are led towards more expert performance (Bedard and Chi, 1993; Chi *et al*., 1988; Ericsson and Simon, 1980).

Rarely do students finish the transition as undergraduates. However, they can make great strides in that transition if provided the necessary information. The authors are currently investigating ways to help civil engineering students transition from novice to expert structural engineers. Their investigation focuses on teaching students how to evaluate the reasonableness of structural analysis and design results. Until now, the methods used to evaluate results were usually considered "experience" and were typically not taught in the classroom. Since the ways engineers evaluate their results are not well documented, the authors began a study to obtain that experience from practicing engineers.

Decision Making versus Knowledge Elicitation

The psychology literature contains a wealth of papers on techniques for gathering information about human thought. Each technique tends to be best suited to obtain a specific type of information. Two types of information that are often sought are about "decision making" and "knowledge". To highlight the difference between the two, consider some of the initial research on decision making done with chess masters (Chase and Simon, 1973a & 1973b). Studying the decision making of a chess master identifies how that master chooses the next move. Research with chess masters showed that they identify patterns of pieces on parts of the board. Once they find a pattern that they recognize, they choose to follow a strategy associated with that pattern. Part of the decision making process is evaluating which strategy to use if multiple patterns are identified. That is important information; however, the novice chess player must learn what the patterns are and what the associated strategies are (knowledge) before they can use this decision making process. Knowledge elicitation techniques are used to discover what the pattern looks like and to then link it with an appropriate strategy. Therefore, knowledge is data stored in the brain, whereas decision making is the process by which the brain uses the data. This paper focuses on techniques for obtaining the data: knowledge elicitation techniques.

Techniques for Knowledge Elicitation

In order to obtain information about experience, the authors chose to consider three different techniques: case study, critical incident, and question-and-answer. There are many techniques in the literature, but these three appeared to be the most appropriate for gathering experience from practicing engineers.

The case study technique provides the interviewee with an example situation to experience or review. The interviewer uses the case study as the focus of the interview. Therefore, the context of the responses is the case selected by the interviewer. An advantage of this technique is that the interviewer is also familiar with the context of the interview. Another advantage of this technique is that the case study activates parts of the interviewee's memory that might not normally be accessible. Because the interviewer provides the case study, the data from all interviewees is limited to the same context: a single project. Therefore, valuable data might be missed because it does not pertain to the project. Another risk is that the interviewer provides a case study that is not sufficiently realistic. If that happens, the interviewee might not be able to produce data, or the data might be invalid (Cordingley, 1989, p. 119).

The critical incident technique was developed by Flanagan (1954). In this technique, the interviewer asks the interviewee to think of a critical incident. This incident then becomes the context of the interview. Once the interviewee recalls the incident, the interviewer asks questions designed to obtain the desired data. One of the primary advantages of this technique is that if the interviewee considers the incident to be "critical" he or she is likely to have a vivid recollection of the incident. Therefore, the information is more likely to be available in conscious memory. Another advantage is that each interviewee provides data from a different incident, so the interviewer is likely to obtain a broader range of data from multiple interviews. Cordingley (1989, p. 121) provides two warnings about this technique: it is not valid for gathering information about decision making, and it might produce atypical information. The first warning is irrelevant to this study, because the desired information is knowledge rather than decision making. The authors address the second warning in the section "Application of Techniques".

In the question-and-answer technique, the interviewer asks direct questions such as "What do you consider when selecting among design options?" The context is the interviewee's job. An advantage of this technique is that the request for information is open ended. The interviewee is able to provide as much data as he or she can remember in response to the questions. However, this technique will produce limited information if the interviewee does not have conscious access to the data (Cordingley, 1989, p. 109).

Application of Techniques

The three techniques were all used during interviews to elicit knowledge from practicing structural engineers. The goal of the interviews was to determine how practicing engineers identify errors in the results of structural analysis and design. The knowledge obtained from the interviews is being used to teach evaluation of structural analysis results in the undergraduate Structural Analysis I and II courses in civil engineering (Hanson, 2006a).

The authors refer to each instance of how practitioners identify the presence of errors as a "tool". An example of one of the tools obtained from the interviews is "compare the weight of the building with the sum of all vertical reactions." The authors have measured the effectiveness of each of the knowledge elicitation techniques as the number of tools identified.

In order to make the interviews as productive as possible, the authors chose to have the structural engineer author conduct the interviews with the practitioners. The familiarity of the subject proved invaluable during the interviews, because often the practitioners needed probing questions in order to access the thought processes used to evaluate results. Someone not familiar with the subject material would probably have left the interviews with insufficient information. To capture as much data as possible, the author chose to record all of the interviews as audio files. The author collected any sketches generated during the interviews so that they could be referenced when reviewing the audio files.

Interviewees

Since the goal was to obtain as many evaluation tools as possible, the authors chose to interview as many practicing structural engineers as reasonably possible. Invitations to participate were sent to a variety of firms. In total, 35 engineers from 9 different firms participated in the interviews. Five of the interviewees were female. The firms spanned the United States geographically from New York to California. The office sizes ranged from 1 to 55 structural engineers. The interviewees' experiences ranged from 1 to 55 years, with a median of 8 years. Only six did not yet have their P.E. license. All of the engineers had college degrees. The distribution of highest degree was 8 Bachelors, 26 Masters, and 1 Doctorate.

Case Study Technique
In order to provide an example project with which the author was familiar, he asked four of the interviewees from different firms to perform schematic design on the project before the interview. The goal was to provide a scenario for which the practitioners would need to evaluate their results. By working on the project within a few days of the interview, the project would be fresh in the memory of the practitioner. Each of the four practitioners spent approximately 20 hours working on the project before the interview. During the interview, the author asked the practitioner to describe the design created and the process used to ensure that the design did not contain errors. The practitioners had little difficulty describing the design and how it was obtained. However, they either struggled to identify how they reviewed their design for errors or admitted that they had not reviewed the design for errors. In total the interviews resulted in less than five tools. Most of those were provided by the author; he identified several errors while reviewing the design with the practitioner.

This technique required a significant investment of time by the interviewee, but produced little information for the authors to use in the classroom. The inefficiency may be linked to the frequency of errors. Most of the practicing engineers indicated that they typically found an error at least daily during the course of their work. However, that translates to identifying approximately one error per eight hours of work. If the interviewer is not present when it occurs, he is depending on the practitioner's ability to be aware of the process used to identify the error and to remember that process later. As previously indicated, in many instances the process is not part of conscious thought or is forgotten as soon as the error is identified.

One option considered but not attempted by the authors was the use of mini case studies. The concept was to provide the interviewee with part of a design and to ask the interviewee to evaluate whether that part of the design was reasonable. The goal would be that the evaluation would take only a few minutes, so each interviewee could review several mini case studies. However, this idea was abandoned for several reasons. In order to evaluate the design for errors, the practicing engineer needs to know about the project: intent, conditions, design philosophy, etc. Preparing mini case studies with sufficient background information would be very time-consuming for the authors. By providing practitioners with only a part of the structure, the authors would be eliminating any holistic approach that a practitioner might take to reviewing results. The other reason that mini case studies were not attempted was that they limit the tools identified to the situations envisioned by the authors. The results obtained using the critical incident technique provided tools that occurred from the initial design phase to the construction phase. The authors would not have been able to envision the breadth of mini case studies necessary to obtain the breadth of tools obtained using critical incident.

Critical Incident Technique
The author used the critical incident technique with all 35 interviewees. The goal was to obtain two tools from each practitioner by utilizing their most accessible memories: memorable events and recent events. Each interview required 15 to 30 minutes. If the interviewee also prepared

the case study, the critical incident technique was usually used after the discussion of the case study. During these interviews, the author began with the request "Think of the most recent time you discovered something unreasonable in the results of analysis or design." Once the practitioner indicated that he or she remembered the incident, the author continued with "Please briefly describe the project." If necessary, the author asked questions to clarify his understanding of the situation. He then followed with the question "What was unreasonable about the result?" After the practitioner's description, the author probed with questions such as "What caught your attention?" or "What would you have expected in that situation?" in order to help the practitioner access the thought processes used to determine whether there was an error. Note that several researchers have indicated that probing to learn about decision making often biases the results (Ericsson and Simon, 1980, p. 221). However, the authors have not found any studies to indicate that probing interferes with the accuracy of knowledge elicited. Once the interviewer had sufficient understanding of the thought processes used in the first incident, he repeated the process. For the second incident, the interviewer requested that the practitioner "Think of the most alarming discovery you have made of something unreasonable."

This technique resulted in the 35 practitioners identifying 67 instances of errors. Of those instances, only twice was the practitioner not able to remember or describe how he or she identified the error. Therefore, this technique was highly productive. In addition, it required no preparation time for the interviewee, and each interview took less than half an hour. All of these interviews were conducted face-to-face; however, it would be possible to conduct them over the phone. Note, however, that sketches were an important part of the communication process between the author and the interviewees. Therefore, phone interviews would need to include the ability to fax sketches back and forth during the conversation.

Question-and-Answer Technique

After the critical incident technique, the author used the question-and-answer technique with each interviewee. During this part of the interview the practitioner was asked "What are common errors you have seen?" Follow-on questions often included probing such as "How do you check for those errors?" This technique resulted in the identification of 20 tools. Question-and-answer required less time than the critical incident technique; however, that was due to the low number of tools identified. In general, the practitioners appeared to struggle to identify the desired information during this part of the interview. Again, this may reflect the subconscious nature of the thought processes involved. In order to recognize the thought process, the interviewee might need to experience a situation where the process is used or have a strong memory of the situation.

Analyzing the Data

The structural engineer author reviewed each of the interview recordings to distill the pertinent data. The goal of this study was to obtain tools for identifying the presence of errors in structural analysis and design results. Therefore, the reviewer created a table with the following headings: What caught the interviewee's attention (the Problem); What happened to bring about the problem (the Error); How interviewee knew that there was a problem (the Tool for evaluating); Audio filename; and Time index. As he reviewed each audio file, the reviewer entered the information in the table. Note that in some cases, the interviewee was not able to determine what brought about the problem, and in two instances the interviewee was not able to remember how he/she knew there was a problem.

Once all of the data was consolidated in one table, the structural engineer author reviewed the tools for commonalities. He was able to divide the tools into six categories: comparisons, rules of thumb, visualization, previous experience, field, and other. The results are described in more detail in an article by Hanson (2006b).

Adapting the Critical Incident Technique for Other Studies

The critical incident technique can produce a wealth of information for instructors to use to help students transition from novice to expert. This technique appears to be well suited for gathering information typically considered "experience". Such experience is typically associated with the higher level cognitive tasks, synthesis and evaluation, as defined by Bloom and Krathwohl (1984). When used with many practitioners, the technique can yield a database of diverse experiences that can be incorporated into course instruction and assignments. Some examples of data for which the critical incident technique is well suited to obtain include the following:

- The criteria designers use to evaluate competing design options.
- The most important factors that designers consider in making a decision about which material(s) to use.

In contrast, eliciting knowledge about low- to mid-level cognitive tasks such as comprehension, application, or analysis (Bloom and Krathwohl, 1984) might be better done using the question-and-answer technique. The case study technique appears to be best suited for eliciting knowledge about *processes* associated with higher level cognitive tasks (synthesis and evaluation). For example, the case study technique is ideal for obtaining detailed information about the design process within a field of engineering.

Lessons Learned

For those desiring to develop a knowledge elicitation study using the critical incident technique, the authors have the following suggestions:

- The interviewer should be knowledgeable in the field of the interviewees. This provides a common language and a basic level of understanding.
- The key to accessing a *critical* incident in the practitioner's memory is to ask for something that is the most (e.g., most recent, most successful, most important).
- Federal regulations in the United States require that all research involving humans as subjects have a protocol reviewed and approved by an oversight organization.
- Anticipate that the first two or three interviews might be less productive as the interviewer learns how to probe for information.
- Prepare and read from a script. This will assure that the interviewer follows the protocol approved for research involving humans as subjects. It also ensures that all of the desired questions are asked in the desired sequence. Have examples of probing questions listed as reminders for the interviewer.
- Practice asking open-ended probing questions that begin with "Why did you …", "How did you …", "What did you …" These will tend to lead to reliable data in the interviews. Questions such as "Did you do this because …" might bias the data or elicit only short responses of yes or no.

- Review the day's interviews before beginning the next set. This allows the interviewer to reflect on which probing questions worked well and which did not. By analyzing the data right away, the interviewer knows whether sufficient detail is being obtained.
- Interview practitioners one at a time. Do not have anyone else in the room. That way, the next person's responses are not influenced. Also, the interviewee is more likely to speak candidly when potentially embarrassing information will not be shared with coworkers or supervisors.
- Interview practitioners from a variety of companies to obtain a broad sampling of data. Engineers at the same company are likely to share the same experiences and philosophies.
- Interview practitioners with a range of experience levels. If the desired data comes best from experiences viewed as "failures", junior engineers appear to be more comfortable with sharing such experiences. Senior engineers, however, have observed a greater variety of "failures".

Additional Resources
There are several resources available to help educators elicit knowledge from practicing engineers. *Eliciting and Analyzing Expert Judgment: A Practical Guide* (Meyer and Booker, 2001) and "Knowledge Elicitation Techniques for Knowledge-Based Systems" (Cordingley, 1989) contain suggestions and checklists for developing and administering an interview program. Two resources for analyzing the data obtained from the interviews are Chi (1997) and Ericsson and Simon (1993).

Summary
The transition from novice to expert requires acquisition of knowledge. In order to help students make that transition, instructors must help provide the pertinent knowledge. Much of that knowledge has been documented in textbooks. However, some instructors desire to help students acquire additional knowledge about their career field; knowledge contained only in the collective memories of the experts. Typically that knowledge is called "experience" and is dismissed as not teachable. The authors have discovered, however, that much of that knowledge can be identified and taught.

Before an instructor can begin to help students acquire the knowledge, the knowledge must be identified. This study has compared the use of three knowledge elicitation techniques for exactly that purpose: case study, critical incident, and question-and-answer. If the instructor is seeking knowledge that consists of cognitive tools that might be based on the practitioner's experience and are not always consciously available, the authors recommend the critical incident technique.

The critical incident technique requires only half an hour of the practitioner's time, and typically produces more information than the case study or question-and-answer techniques. If necessary, the technique can be conducted over the phone.

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