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Ill-structured problems and the reference consultation
The librarian's role in developing student expertise

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Abstract
Purpose – To apply the concept of ill-structured problems and learner expertise to the reference consultation.
Design/methodology/approach – Research literature from the 1960s forward regarding ill-structured problems and learner expertise in a variety of disciplines was surveyed. Resulting characteristics of expert problem-solvers were used to suggest applications to the reference consultation.
Findings – Librarians can structure the reference consultation to better meet students' needs as information problem solvers.
Research limitations/implications – The method described appears to have sound basis in research into cognitive development and reflective thinking, but it has not been empirically demonstrated in the reference environment. Empirical research with reference librarians and students would be a logical next step.
Originality/value – Research into ill-structured problems and learner expertise is ongoing in information retrieval systems. It has not been applied to the reference consultation.

Introduction

As students enter the twenty-first century university, many librarians mistakenly assume that these students' frequently touted comfort with technology makes them more ready for the development of information literacy than they really are. Unfortunately, these entering students almost always are novices in the subject domains they are studying, just as they are novices in what might be termed the "secondary" domains of information relating to those subject areas. Their dual lack of expertise compounds the fact that many of the information-related problems that send them to the reference desk could be classified as "ill-structured" information problems. Ill-structured problems are problems with indefinite starting points, multiple and arguable solutions, and unclear maps for finding one's way through information. These problem's often ask students to deal with complex multi-focal social and moral issues. Learning to wrestle with them, however, equips students to face similar problems once they embark on their personal and professional lives beyond the university.

Considerable attention has been paid to novices and their approaches to problem solving in certain domains such as physics and engineering. In the realm of information science attention is being devoted to designing information retrievalsystems that will help students find paths through information in order to solve ill-structured problems in many different domains (Cole and Leide, 2003; Cole *et al*., 2005; Hembrooke *et al*., 2005; Leide *et al*., 2003). Little or no attention, however, has been devoted to the information novice – the student – and the information expert – the reference librarian – working together to solve ill-structured problems involving finding, evaluating, and using information.

Effective problem solving is closely linked with reflective thinking which Dewey defines as “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends” (Dewey, 1933, p. 9). Dewey divides such thinking into two main components: “a state of doubt, hesitation, perplexity, mental difficulty, in which thinking originates” and “an act of searching, hunting, inquiring to find material that will resolve the doubt, settle and dispose of the perplexity” (Dewey, 1933, p. 15). Baron closely models his five phases of reflective thinking on Dewey:

> . . . problem recognition, enumeration of possibilities, reasoning (search for, or recognition of, evidence bearing on the possibilities), revision (use of the evidence), and evaluation of the possibilities to decide whether more thinking is required (Baron, 1981, p. 295).

Both Dewey and Baron emphasize evaluating and defending one’s thinking and beliefs as a key element of reflective thinking. Both Dewey and Baron also bring to mind the Association of College and Research Libraries (ACRL, 2000) Information Literacy standards:

- determine the extent of information needed;
- access the needed information effectively and efficiently;
- evaluate information and its sources critically;
- incorporate selected information into one’s knowledge base;
- use information effectively to accomplish a specific purpose;
- understand the economic, legal, and social issues surrounding the use of information, and
- access and use information ethically and legally.

While reference librarians may attempt to promote reflective thinking by integrating the ACRL information literacy standards into reference consultations, many would have to admit that because of time constraints they often have to limit themselves to ACRL’s “locating information” standard at the expense of the others, especially “determining information need”, and “evaluating and applying information”, both probably more critical to reflective thinking than locating information. Reference librarians, however, can play an expanded role in developing reflective thinking with regard to information in the subject domains as they coach patrons in solving ill-structured information problems. Interaction between the student and the reference librarian as they solve these information problems helps move the student along a continuum from information novice to information expert.

Well-structured and ill-structured problems

As defined by Newell and Simon:

> A person is confronted with a *problem* (emphasis Newell and Simon’s) when he wants something and does not know immediately what series of actions he can perform to get it (Newell and Simon, 1972, p. 72).

Some problems stay in the classroom; others students bring to the reference consultation.

Problems are often divided into two basic categories, well-structured and ill-structured, with gradations in between. A well-structured problem has a clear starting point or "given" (Lovett, 2003, p. 723), has clear goals, and the answer generally can be agreed on. Newell and Simon narrowly limit the definition of a well-structured problem (called by them "well defined"): "A problem . . . is *well defined* (emphasis Newell and Simon's) if a test exists, performable by the system, that will determine whether an object proposed as a solution is in fact a solution" (Newell and Simon, 1972, p. 73). They further limit the definition by specifying that "performable" means "with a relatively small amount of processing effort" (Newell and Simon, 1972, p. 73). Jonassen considers puzzle problems a sub-category of well-structured problems. "Domain independent" and "de-contextualized", these problems have "a single correct answer where all elements required for the solution are known and solutions require using logical, algorithmic processes" (Jonassen, 1997, p. 67). An example of this type of problem is the classic problem of cannibals and missionaries having to share a limited number of canoes in order to cross the river.

An ill-structured problem, on the other hand, lacks a starting point, a goal, a solution, or all three. Furthermore, according to Estes, "there is no simple 'legal move generator' for finding all of the alternative possibilities at each step" (Estes, 1975, p. 286). Ill-structured problems often involve multiple subject domains and "require learners to express personal opinions or beliefs...and make judgments" (Jonassen, 1997, p. 69) in ways well-defined problems do not. Ackoff extends the single category of ill-structured problems to the more complex category of a "mess", or a "system of problems" (Ackoff, 1974, p. 21), noting that – other than in the classroom –problems rarely occur in a vacuum. They intersect with problems in other disciplines or arenas of life, and the apparent solution of one problem often creates a new problem in its place. Ill-structured problems invite a certain level of relativity of judgment. Voss and Post suggest that an ill-structured problem's solution can be considered "good if other solvers find little wrong with it and think it will work" (Voss and Post, 1988, p. 281). They make the particularly interesting qualification that those judging the solution should have a similar level of expertise as the one offering it.

Checkland calls well-structured problems "hard" because they have "relatively sharp boundaries and well-defined constraints. Appropriate information flows for the decision process are capable of clear definition, and, most important, what the analyst will recognize as 'a solution' to the problem is clear". Ill-structured problems he calls "soft" because "all (the previously mentioned) elements are themselves problematical. Here many objectives are unclear, some important variables are unquantifiable, and the analysis will necessarily have to include examining the value systems underlying the various possible objectives" (Checkland, 1985, p. 155) Jonassen (1997) considers well-structured, non-puzzle problems to be more domain-dependent than puzzle problems but stresses that the problem-solving skills they develop are useful only for solving other well-structured problems, usually at the end of textbook chapters. These skills do not transfer well to solving ill-structured problems, which usually occur in real life outside the classroom and thus often have to do with the social sciences and humanities, even when they are centered within scientific domains.

Quade and Miser (1985, pp. 14-15) list a number of factors that may complicate real-world problems, regardless of type, including:

- inadequate knowledge and data;
- many disciplines involved;

- inadequate existing approaches;
- unclear goals and shifting objectives;
- pluralistic responsibilities;
- resistance to change in social systems; and
- complexity.

In Table I, saving the pedestrians from the speeding car exemplifies a well-structured problem. The variables are clear, the value to be solved for – time – is well-defined, and everyone in the class should be able to agree on the correct answer if they use the correct formula. As Jonassen (2000) points out, however, well-structured questions are not always simple, nor are ill-structured questions always complex. The temperature comparison problem exemplifies a more complex, yet still well-structured problem because average monthly temperatures can be concretely determined for different latitudes along the Equator using well-accepted methods available to students in a typical meteorology or geography class.

The question of whether to allow full credit for late assignments is an ill-structured problem, but a rather simple one. Students probably will have conflicting opinions, some more supportable than others. It may not be possible to reach consensus. But the decision has few ramifications outside the door of the classroom, and by the next semester everyone will probably have forgotten about the whole issue. On the other hand, finding a way to provide dental care to poor families is both ill-structured and complex, involving a whole system of problems, a "mess" in Ackoff's terms. What levels of care should be provided – teeth cleanings, fluoride treatments, amalgam fillings of a limited number? Should children be covered up to a certain age, but not adults? Must all dentists provide some free care? Will the government reimburse them?

While students rarely present puzzle problems at the reference desk, they do bring other well-structured problems, ill-structured problems – including messes – and problems that fall somewhere in between. These are also represented in Table I.

The first reference question is well-structured. It has a clearly defined goal, finding the review of *Seabiscuit*. While the path between the problem and its solution is at first unclear to the student, with some instruction from a librarian on how to use a database like Academic Search Premier to find current movie reviews the student should be able to "solve" the problem.

The question of determining whether or not an article has been peer-reviewed is complex but still well-structured because it is actually several well-structured problems combined into one. Parsing the complex problem into its parts is the first step required for solving the overall problem: Defining "peer reviewed" constitutes the first part of the problem. The second part of the problem involves determining whether the journal in which the article is published uses a peer review system. Finally, the student needs to determine whether the particular article in question would have been peer reviewed. Again with help from a librarian, the student can solve the sub-problems and the larger complex problem with an acceptable degree of certainty by using tools such as Ulrich's, examining the characteristics of the article (does it report primary research, for example), visiting the publisher's web site, and possibly examining a hard copy of the journal itself.

The question of finding an entertaining book to read over a free weekend is ill-structured but simple. The student may have only a vague idea of what he means by "entertaining", and his idea and the librarian's interpretation of that idea as expressed may well differ. Even when the student has finished reading the book he may not be sure how well it met his needs. But in the end, this is a one-time need of little lasting import.

Table I. Examples of problem types

Problem type	Classroom problems	Reference problems
Well-structured (puzzle)	Three missionaries and three cannibals need to cross a river using a canoe that holds only two. Obviously, the cannibals can never outnumber the missionaries, either in the canoe or on the shore. How can they all cross safely?	(Not applicable)
Well-structured	A 3,000 lb. car is parked on a hill. The hill has an incline of 15 degrees and is 200 feet long. The car's brakes fail. How much time do the pedestrians at the bottom of the hill have to get out of the way?	Where can I find a review of the movie *Seabiscuit*?
Well-structured, complex	Compare the 12 average monthly temperatures along ten different points of latitude along the equator	How can I tell if this article is peer-reviewed?
Ill-structured, simple	Should your classmates who turn in their assignments late receive full credit for them?	I have got some spare time this weekend. Can you help me find a book that's fun to read?
Ill-structured (mess)	How can we ensure that poor families receive the dental care they need?	I need to design a magnet school that meets the needs of working parents. Where can I find information about magnet schools and working parents?

On the other hand, designing a plan for a magnet school that meets the needs of working parents exemplifies a complex ill-structured problem that the student might eventually encounter in the working world. The goal, a school that addresses working parents' needs, is stated. The givens, the needs of working parents, are not explicitly identified, however. In fact, it may be impossible to agree completely on what those needs are. Similarly, it will be difficult to agree on what constitutes "meeting" those needs; for instance, how many different needs are met, how well a specific need is met, or a combination of those factors. This ill-structured problem also strays into the territory of a "mess" because creating this school almost inevitably will divert resources from other areas of the school district's budget and cause new problems. For example, providing after-school care beyond 6 p.m. may require funds that otherwise would be used to pay for school nurses. How will the district fill the gap in meeting student health needs that school nurses ordinarily address?

Problems rarely are either clearly well- or ill-structured, but rather are more or less well- or ill-structured depending on clarity of their various components "at some points" (Reitman, 1965, p. 301) during problem solving. The real value in distinguishing the different types of questions, notes Checkland, is that one "may formulate the hard (well-structured) aspects with precision, marshaling the proper intellectual tools (often quantitative ones), and proceed to make appropriately different kinds of explorations of the softer (ill-structured) aspects" (Checkland, 1985, p. 155).

Much of the interest in differentiating well-structured from ill-structured problems originated from research into artificial intelligence in the 1960s and 1970s as computer scientists explored the similarities and differences between computers and human minds as "problem-solving machines" (Churchman, 1971, p. 22). Newell and Simon's reference to an "information processing system" (Newell and Simon, 1972, p. 73) reinforces this connection. Newell and

Simon (1976) refer to the "problem space", a term that has become fundamental to subsequent discussions of problem solving. They define the problem space as "a space of symbol structures in which problem situations, including the initial and goal situations, can be presented" (Newell and Simon, 1976, p. 121). Newell and Simon (1972) posited that solving ill-structured problems was made possible by the human or machine problem solver dividing up the problem into sub-parts and moving from decision point to decision point within the problem space, reducing the size of the space and the number of choices to be made until the goal was reached. As Simon (1973) later claimed, through this process questions became increasingly well-structured and thus solvable.

Others (Baron, 1981; Dewey, 1933; Meachem and Emont, 1989; Schon, 1991) have stressed the importance of discriminating the problem content from the problem solution. In fact, Schon warns that too much attention to problem solving diverts necessary attention from "problem setting":

> When we set the problem, we select what we will treat as the "things" of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed (Schon, 1991, p. 40).

Novice and expert problem solvers

Attention to the relationship between problem solving and learning has grown recently. Physics teachers particularly have led the way in this regard. Along with interest in problem structure and learners has come investigation into the differences between novice and expert problem solvers. Just as problem structures range along a continuum, so do problem solvers range along a continuum from novice to expert. Examining the characteristics of those at the farthest ends of the spectrum (see Table II) is a useful starting point for discussion.

At the most advanced end of the spectrum, Chi and Glaser (1988) describe domain experts of all kinds as sharing a common set of characteristics:

- Their expertise is domain-specific, at least partially due to the quantity of their knowledge of that domain. Just because one is an expert in one domain does not guarantee at all that one will be an expert in another domain.
- Their knowledge base is well-organized and thus they can see patterns within it.
- They can solve problems quickly because they have had ample practice and can recognize problem patterns. Such quick recognition often automatically sets problem solving into motion.
- Both their short- and long-term memory capacity is greater because many of their problem-solving skills are so automatic that memory is freed from having to store these skills.
- Their problem representations are more deeply structured than novices. They often visualize problems pictorially rather than jumping directly to equations or other problem solving procedures.
- When first presented with a problem they spend more time analyzing it in order to fit it into its appropriate categories.
- They are better than novices at monitoring their own progress, discerning their mistakes, and making necessary mid-course corrections.

Echoing Newell and Simon, Hunt observed that novice problem solvers reason “backwards”, beginning with the goal and moving backwards to the problem’s beginning. On the other hand, expert problem solvers move “forward” through the problem space, constantly making small decisions to reach a solution (Hunt, 1994, p. 226). Unlike experts, novices are hampered in their problem solving by a lack of domain knowledge and a lack of practice solving problems within the domain. Furthermore, if they have some domain knowledge they may be so overwhelmed by its quantity that they cannot determine what is or is not relevant.

When considering the differences between novices and experts, as Sinnott (1989, p. 74) points out, it is also important to keep in mind “developmental differences in assumptions about the nature of knowable reality”. Perry (1970) was one of the first to describe a taxonomy of developmental stages in epistemological confidence. Perry’s taxonomy listed “dualism” (absolute answers are dispensed by an authority figure, such as a professor), “multiplicity” (various answers are equally valid), “relativism” (context and situation support some answers better than others), and finally “commitment” (students take responsibility for defending and owning their choices).

Alexander, who applies research into the novice/expert distinction to school age children, describes a novice/expert continuum with three stages: acclimation, competence, and expertise. Each of these levels is differentiated by the breadth and depth of the problem solver’s knowledge base and by the varying levels of reliance on surface-level versus deep-processing strategies. At the acclimation stage “learners have limited and fragmented knowledge . . . Also the domain-specific tasks these students encounter in schools are commonly novel and challenging, thereby prompting frequent use of surface-level strategies”. Relying on surface-level strategies, a student might immediately attempt to solve the runaway car problem in the same way he previously solved another runaway car problem without first analyzing the deeper structure of the problem at hand. She might not look for differences between the two problems beyond the quantitative aspects of incline, weight, and distance. Competent learners, on the other hand, use “a mix of surface-level and deep-processing strategies” as they become more familiar with typical problems in the domain. Finally, experts have a both a deep and wide knowledge base and a full repertoire of deep-processing problem-solving strategies (Alexander, 2003, pp. 11-12).

Groen and Patel also list gradations of expertise:

- novices (“with no self-taught knowledge and no (formal or informal) training in the domain”);
- “intermediates” (“whose knowledge of the domain is somewhere between that of a novice and an expert”);
- “subexperts” (“who have expertise in a closely related domain”, for instance, expertise in gross anatomy but no clinical expertise in heart surgery); and
- experts (who have “demonstrable mastery of the domain” as measured against some kind of criteria) (Groen and Patel, 1991, pp. 40-41).

Groen and Patel (1991, p. 41) also credit some novices with having certain kinds of “common sense” expertise that allow them to solve problems better than some intermediates. While novices may have an inadequate knowledge base in the content domain, their intermediate counterparts may be equally handicapped by excessive irrelevant knowledge that they cannot adequately sort through. The most important part of learning then becomes not just learning to “solve problems” but to defend the choices one has made in their solutions. Furthermore, Hatano and Oura (2003, p. 28) point out that even experts sometimes may be subdivided into those with

Table II. Characteristics of novice and expert problem solvers

Primary subject domain		Information literacy (secondary) subject domain	
Novice	Expert	Novice	Expert
Knowledge base is general and limited	Knowledge base is extensive	Knowledge limited to awareness of OPAC and possibly a general periodical database. No knowledge of specialized information tools and resources within the primary subject domain. Unable to maximize features of search interfaces	Extensive familiarity with information tools and resources relevant to the primary subject domain. Able to maximize features of search interfaces
Knowledge base is disorganized	Knowledge base is well-organized	No awareness of appropriateness of different tools and resources to different needs nor how information is structured and organized within the primary subject domain. Limited ability to systematize research	Familiarity with the organization and structure of information within the primary subject domain allows systematic approach to research
Tends to solve problems on a trial and error basis. Works from the hoped-for answer backwards	Extensive practice results in ability to recognize wide variety of problem patterns and ability to solve problems quickly. Works "forward" from the problem statement towards a solution	Tends to use overly broad or narrow natural language searches on a hit and miss basis. No logical overall search strategy	Recognizes patterns of information needs; conceptualizes the information need in order to select tools, keywords, subject headings, and strategies
Problem solving places high degree of load on short-term memory	Less load on short-term memory because memory not taken up with routine problem-solving skills	Has difficulty with complex searches, e.g. using Boolean operators	Routine nature of many research skills allows more time for other aspects of problem-solving, e.g. problem analysis and evaluation of search results
Problem representations are surface-level	Problem representations are deeply structured	Searches limited to using words supplied by assignment, finding the specified number and type of resources, etc	Subdivides problems into sub-concepts. Represents problems in terms of Boolean and proximity operators. Can cognitively map alternative strategies
Jumps quickly into problem solving without analyzing and defining the problem space	Spends time analyzing the problem in order to categorize it appropriately and select appropriate possible solution strategies	Little or no analysis of information need	Analyzes information need. Conceptualized information needs in terms of broader, narrower, related concepts. Determines what information is not needed, as well as what is needed
Stops when a solution is found; little analysis or evaluation of the quality of solution	Monitors own progress, discerns mistakes, makes mid-course corrections. Analyzes and evaluates solutions; reiterates as necessary	Accepts first resources found without analyzing their applicability to information need	Evaluates information found in terms of the information need. Revises the problem statement and search strategy as necessary

“routine” expertise; that is, who do things well but in a procedural fashion, and those with “adaptive” expertise who are more creative, self-aware, and flexible.

Inter-domain differences also may characterize novices and experts. Wineburg (1991) distinguishes historian experts from the physics experts studied by Chi and Glaser (1988) by observing that the experts he studied seemed not to set in motion problem-solving schemes they had developed (perhaps subconsciously) as their expertise grew but to develop problem-solving schemes appropriate to a specific event which they had not previously dealt with in a particular way. Novices assigned the task of drawing conclusions about the Battle of Lexington by examining a set of primary documents and paintings approached the problem in a much more superficial and hit-or-miss fashion. Historian experts – even those who were not experts in American history – were able to work with materials on a deeper level than novices because they understood “how historical knowledge is constructed” (Wineburg, 1991, p. 84).

Furthermore, Smith points out that there are good novice problem solvers, as well as good expert problem solvers; and they share certain characteristics. Good problem solvers, at whatever point on the novice-expert continuum, are able to redescribe (Smith, 1991, p. 12) the problem space in terms that fit the solver’s knowledge base and understanding. They are able to choose appropriate procedures to solve the problem and adjust their approaches as they move through the problem space. Finally, they evaluate their solutions. Experts differ from novices in the extent of their knowledge of the content domain, their repertoire of problem-solving strategies, and the extent of their experience with problem solving in the content domain which allows them to recognize a wider variety of problem patterns.

Problems, expertise, and the reference environment

Librarians and students consulting in the reference environment often must negotiate complex interactions between primary subject domains, for instance, political science, and secondary domains of information literacy in those subjects, for instance, the literature of political science. Librarians are usually considered experts in general and sometimes subject-specific information literacy domains. They may or may not be more expert than the student in terms of the primary subject domain, however.

The basic ACRL information literacy standards address determining need; accessing, evaluating, and incorporating information; and appreciating the social and related contexts of information. These will be interpreted differently across different primary subject domains and problem structures. For example, students of chemistry need to know how to use the *CRC Handbook of Chemistry and Physics*, how to translate a citation’s abbreviated journal title into a complete title in order to check for library holdings, and need to be able to assess the validity and reliability of experimental results they find reported in the literature. Education students need to be able to mine the free Web for lesson plans, need to know how to conceptualize action research projects well-supported by scholarly research, and need to learn how to develop information literacy competencies and dispositions in their own students. English majors need to understand and appreciate the difference between primary and secondary research materials, the uses of reference tools such as the *Oxford English Dictionary*, and how to distinguish between the more and less authoritative literary interpretations they may find using Google Scholar or the *MLA International Bibliography*.

Cole *et al*. (2005, p. 685) point out that an information literacy domain novice often begins interacting with an information retrieval system, such as an online library catalog, before having fully specified her information need, floundering around within the system. On the other hand, an expert has the knowledge base and familiarity with "the knowledge store" represented by the system and consequently is much more capable of using the system for solving problems. The goal of much current research in information retrieval systems and ill-structured problems (Cole and Leide, 2003; Cole *et al*., 2005; Hembrooke *et al*., 2005; Leide *et al*., 2003) is to make systems friendlier to domain novice users, providing interactive feedback, guideposts and decision aids along the way as the novice navigates the system.

Hembrooke *et al*. (2005) have investigated the way in which the feedback provided to novices by a search interface such as Google (for example, numbers of results and ordering) affects novices' ability to refine their searches productively. This research suggests that some interfaces currently under development eventually may be able to distinguish novice from expert problem solvers by their search strategies and may be able to offer novices ways to interact with these search interfaces in order to help them make more fluent progress towards their problem solving goals.

All of this research reflects behind the scenes developments in information architecture and retrieval systems the fruits of which may lie years down the road. Research does not address how the reference librarian's ability to distinguish well-structured from ill-structured questions in the information environment might inform the reference consultation. Research also does address how reference librarians might apply understanding of the differences between domain novice and domain expert problem solvers to the reference consultation in order to develop student expertise.

Engineering and physics educators have led the way in studying problem solving and devising instructional strategies that will move students along the road to expertise. For example, the Accreditation Board for Engineering and Technology (ABET) lists "an ability to identify, formulate, and solve engineering problems" as one of the general criteria for basic level engineering programs (Accreditation Board for Engineering and Technology, 2004). To bring the curriculum of the Bucknell University undergraduate engineering program more into line with the ABET goals for improving student expertise, Prince and Hoyt describe the integration of increasingly ill-defined problems into the curriculum, along with the problem solving skills necessary for solving increasingly "ambiguous" problems. Courses labeled P1, P2 and P3 range from courses that stress "well-defined problems having unique solutions and often unique solution methodologies" to higher level courses that stress "poorly defined problem statements, goals or both with multiple solutions and solution methodologies possible" (Prince and Hoyt, 2002, pp. F2A8-9)). By aligning problem solving skills in these courses with Bloom's (1974) Taxonomy of identification, comprehension, application, analysis, synthesis and evaluation, the curriculum is better able to improve students' problem solving expertise. Well-defined problems, for example, require students only to identify the type of problem, comprehend the kinds of strategies, equations, and tools that might be appropriate for the problem's solution, and apply those strategies, equations, and tools in order to solve the problem. More ill-structured problems not only will require those levels of thinking but much more elaborate problem analysis, synthesizing of previous learning, and constant self-evaluation as students move through the problem spaces.

Lajoie (2003) surveys research that demonstrates how studies of expert problem solving in domains as disparate as avionics and surgical intensive care nursing can be used to generate problem-solving models for use with novice and intermediate problem-solvers at all academic levels. One example, dynamic assessment, is "a moment-by-moment assessment of learners during problem solving so that feedback can be provided in the context of the activity" (Lajoie, 2003, p. 22). Although instructors can dynamically assess learning interactively with technology, they also can accomplish it by working in person with students. Lajoie also describes the use of multi-media to demonstrate examples of intermediate and expert problem solving. By watching others model expert problem solving behaviors students begin to approach problems more expertly, too.

Because the reference librarian usually works individually with students during the reference consultation, he can take advantage of the social interaction that several researchers see as an invaluable aid to helping learners become more expert problem solvers. Meachem and Emont (1989) for instance, claim that in order to solve a problem successfully a learner needs to escape a mental "rut", often best done in "conversations" with others "as friends suggest new ways of thinking about situations, point to inconsistencies in our logic, provide a counterbalance to our emotional attachments in the situation, and suggest new means for solving our problems" (Meachem and Emont, 1989, p. 10). In two studies of engineering students, Wetzstein and Hacker (2004) demonstrated that interacting with a live, rather than virtual, partner improved students' problem solving abilities because the "reflective verbalization" that resulted from prompting from a partner led to more in depth solutions than the mere correction of surface errors found in the control groups. They conclude that a "dialogue-specific question-answering style of verbalization gives rise to a specific way of thinking, that is an analytic solution style, including essential conceptual relations, especially final, conditional and causal ones" (Wetzstein and Hacker, 2004, p. 153). Their results further confirm the social nature of problem-solving.

When cognitive psychologists discuss knowledge construction they often use the term "scaffolding" to denote the prompts, questions, and other aids provided to learners to aid in developing cognitive thinking. To be effective these scaffolds need to fall within the learner's "zone of proximal development". The fundamental concept of the zone of proximal development was named by Vygotsky (1978, p. 86) and defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers". That is, learners need to be encouraged and even pushed to move beyond their present level of knowledge, but the moves must be graduated so as not to fall completely outside the learner's knowledge base and developmental stage. Elmborg (2002) points out that reference librarians are often unintentionally guilty of operating outside of the student's zone of proximal development. They treat students as though they were as expert as the librarians themselves, even though librarians know this probably is not the case. One solution, Elmborg suggests, is for librarians to ask more questions; in other words, to provide more scaffolds for student learning.

Xun and Land (2004) distinguish between "hard" and "soft" scaffolds. Hard scaffolds are those that are predetermined and set, for instance in a simple, non-dynamic online tutorial environment. Soft scaffolds are provided by human interaction, either with peers or with teachers who can constantly adjust their prompts to the student's actions (Xun and Land, 2004). If a paper assignment in a literature class asked the student to choose an image and analyze its use in a particular novel, examples of soft prompts in a student-teacher conference might include:

- Where do you find examples of this image that do not exactly fit with the pattern you are developing?
- Does that mean that your interpretation is wrong? Why or why not?

- With what characters do you find this image to be most closely associated?

Each of these prompts is meant to encourage the student to reflect on what she has written so far in order to push her analysis of the imagery to a deeper level.

Librarians can provide these soft scaffolds, too, within the social environment of the reference consultation. A key first step is helping the student determine how well- or ill-structured the problem is, although the librarian probably will not use those terms *per se*. Does the student have a predetermined topic, or does she have a degree of latitude in choosing her topic? How specific is her goal, either as stated in the assignment itself or as articulated by the student? Does the student have wide berth as to the number and kinds of resources she is encouraged or allowed to use?

With a grasp on the nature of the problem, the librarian and student can begin to solve the problem, with the librarian building into the reference consultation scaffolding questions designed to build information problem solving expertise within the given subject domain. Librarian prompts can encourage the student's reflective thinking thus leading to improved problem setting and problem solving.

The characteristics of expertise suggested by Chi and Glaser (1988) and summarized in Table II suggest further questions that the librarian can build into the reference consultation.

Because expertise is domain-specific and is at least partially dependent on the quantity of the student's knowledge within that domain, the librarian could continue the consultation with such questions as "What level class is this for?" and "How much do you already know about this topic?" in order to determine how advanced the student's knowledge is. If the librarian detects that the student's level of interest in the topic is low, he may be able to help the student adapt the topic's focus to one which the student has more expertise and more interest. In some cases, the librarian may have a level of expertise in the primary subject domain that is no higher than the student's. In these cases, asking the student to define terms and explain what she already understands about the problem not only will help the librarian but should help the student articulate her "tacit knowledge" (Polanyi, 1967), the things she may know too well explain but which may need articulation in order to set the problem effectively.

The expert's knowledge base is well-organized, allowing the expert to see patterns within it. To help the student perceive patterns within her knowledge base the librarian could ask the student, "How does this topic fit with other topics you have worked on for this class or for your major?" and "What similarities and differences have you found so far between this problem and others you have worked on?"

Experts can solve problems quickly because they have had ample practice and because recognizing problem patterns often automatically sets problem solving into motion. The librarian can ask the student:

- What library tools and resources have you used before?
- How did you approach other information problems like this one?
- What worked?
- What did not work?

Such questions may spark recognition on the student's part of similar problem categories previously attempted and solved; for instance, problems requiring statistical sources or autobiographical materials.

Experts' short- and long-term memory capacity is greater because many of their problem-solving skills are so automatic that memory is not required for storing them. While students may not have developed their problem-solving skills to the level of an expert, prompts from a reference librarian can remind them of a skill they do already do know that can be transferred to the library environment. For instance, how is a keyword search in Google similar to a keyword search of the library's OPAC?

Experts' problem representations are more deeply structured than novices. As Harper points out, novices can be encouraged to represent problems more fruitfully if they are reminded of fundamental principles that might apply (Harper, 2004). For instance, if the reference librarian teaches a student the principle of using the Boolean operator "and", when the need for using that operator appears later in the same reference consultation, the librarian can prompt the student, "Do you remember what I told you a little while ago about combining concepts? Go ahead and combine these terms the same way."

Experts spend more time analyzing a problem when they first encounter it in order to fit it into its appropriate categories. Perhaps one of the most valuable gifts reference librarians can give their students when working one-on-one in a consultation is the gift of time. While librarians correctly perceive that students are often in a hurry to find whatever information they can as fast as they can, that assumption can be incorrect and can even give students the misimpression that they are inconveniencing the librarian. When the librarian takes the time to ask the student questions such as, "What kind of a question is this? Is it asking you to compare or contrast? To categorize? To describe? To chronicle? Given this kind of question, what kinds of information do you need?" the librarian models for the student the preliminary problem analysis that will benefit the novice problem solver in the long run. Taking out a piece of paper and sketching out one possible graphic representation of the problem, for instance in a concept map format, is another way to model problem analysis for the student.

Finally, experts are better than novices at monitoring their progress, discerning their mistakes, and making necessary mid-course corrections. The librarian can encourage the student to think aloud during the search, asking the student, "Tell me what you are doing. Why did you make that choice?" Through thinking aloud, students actually may lead themselves to better solution paths.

Using any of these kinds of scaffolding prompts, librarians risk sounding patronizing and overly didactic. Thinking of oneself as a coach who is encouraging the student's reflective thinking should help reduce this risk. Stover (2004) suggests a particularly interesting way of negotiating the gap between information "novice" student and information "expert" librarian. He compares the reference librarian to the post-modern psychotherapist who chooses the "posture of non-expertise" (Stover, 2004, p. 274) in relation to the patient. This stance transfers expertise to the interaction between the librarian and the student rather than "embed[ding]" (Stover, 2004, p. 278) it in the librarian alone. Otherwise, the librarian is expected to have all the answers, thus disempowering the student. In Stover's model reference becomes "a conversation, not a monologue, in which the librarian . . . and the client together construct the information scenario" (Stover, 2004, p. 286). Both student and librarian are experts. The student contributes her expertise within the subject domain (at whatever level that may be) and her knowledge of her problem; the librarian contributes his expertise as a problem solver in the information literacy domain.

Solving ill-structured problems is fundamental to the development of reflective thinking, and reflective thinking is fundamental to the development of expertise in solving ill-structured problems. Reference librarians can play a formative role in helping students become more expert information problem solvers by incorporating awareness of the information search as an often ill-structured problem and the student as an information novice on the way to expertise. Librarians who are aware of the range of problem structures and the range of problem solving expertise levels can incorporate reflective thinking into the reference consultation, increase learner expertise in information literacy, and enhance the student-librarian partnership.

References

Accreditation Board for Engineering and Technology (2004), *2005-2006 Criteria for Accrediting Engineering Programs*, available at: www.abet.org/Linked%20Documents-UPDATE/ Criteria%20and%20PP/05-06-EAC% (accessed November 23, 2005).

Ackoff, R.L. (1974), *Redesigning the Future: A Systems Approach to Societal Programs*, Wiley, New York, NY.

Alexander, P.A. (2003), "The development of expertise: the journey from acclimation to proficiency", *Educational Researcher*, Vol. 32 No. 8, pp. 10-14.

Association of College and Research Libraries (2000), *Information Literacy Competency Standards for Higher Education*, American Library Association, Chicago, IL.

Baron, J. (1981), "Reflective thinking as a goal of education", *Intelligence*, Vol. 5, pp. 291-309.

Bloom, B.S. (1974), *Taxonomy of Educational Objectives*; The Classification of Educational Goals, D. McKay, New York, NY.

Checkland, P.B. (1985), "Formulating problems for systems analysis", in Miser, H.J. and Quade, E.S. (Eds), *Handbook of Systems Analysis: Overview of Uses, Procedures, Applications, and Practice*, North-Holland, New York, NY, pp. 151-70.

Chi, M.T.H. and Glaser, R. (1988), "Overview", in Chi, M.T.H., Glaser, R. and Farr, M.J. (Eds), *The Nature of Expertise*, Lawrence Erlbaum, Hillsdale, NJ, pp. xv-xxvii.

Churchman, C. (1971), *The Design of Inquiring Systems: Basic Concepts of Systems and Organization, Basic Books*, New York, NY.

Cole, C. and Leide, J.E. (2003), "Using the user's mental model to guide the integration of information space into information need", *Journal of the American Society for Information Science and Technology*, Vol. 54 No. 1, pp. 39-46.

Cole, C., Large, A. and Leide, J.E. (2005), "Putting it together online: information need identification for the domain novice user", *Journal of the American Society for Information Science and Technology*, Vol. 56 No. 7, pp. 684-94.

Dewey, J. (1933), *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process*, D.C. Heath, Boston, MA.

Elmborg, J.K. (2002), "Teaching at the desk: toward a reference pedagogy", *portal: Libraries and the Academy*, Vol. 2 No. 3, pp. 455-64.

Estes, W.K. (Ed.) (1975), *Handbook of Learning and Cognitive Processes*, Lawrence Erlbaum, Hillsdale, NJ.

Groen, G.J. and Patel, V.L. (1991), "A view from medicine", in Smith, M.U. (Ed.), *Toward a Unified Theory of Problem Solving: View from the Content Domains, Lawrence Erlbaum, Hillsdale*, NJ, pp. 35-44.

Harper, K.A. (2004), "Expert-novice comparisons to illuminate differences in perceptions of problem solutions", *AIP Conference Proceedings*, No. 720, pp. 129-132.

Hatano, G. and Oura, Y. (2003), "Commentary: reconceptualizing school learning using insight From expertise research", *Educational Researcher*, Vol. 32 No. 8, pp. 26-9.

Hembrooke, H.A., Gay, G.K. and Granka, L.A. (2005), "The effects of expertise and feedback on search term selection and subsequent learning", *Journal of the American Society for Information Science and Technology*, Vol. 56 No. 8, pp. 861-71.

Hunt, E. (1994), "Problem solving", in Sternberg, R.J. (Ed.), *Thinking and Problem Solving, Academic Press*, San Diego, CA, pp. 215-31.

Jonassen, D.H. (1997), "Instructional design models for well-structured and ill-structured problem-solving learning outcomes", *Educational Technology Research and Development*, Vol. 45 No. 1, pp. 65-94.

Jonassen, D.H. (2000), "Toward a design theory of problem solving", *Educational Technology Research and Development*, Vol. 48 No. 4, pp. 63-85.

Lajoie, S.P. (2003), "Transitions and trajectories for studies of expertise", *Educational Researcher*, Vol. 32 No. 8,

pp. 21-5.
Leide, J.E., Beheshti, J. and Large, A. (2003), "Visualization schemes for domain novices exploring a topic space: the navigation classification scheme", *Information Processing & Management*, Vol. 39 No. 6, pp. 923-40.
Lovett, M.C. (2003), "Problem-solving", in Nadel, L. (Ed.), *Encyclopedia of Cognitive Science*, Nature Publishing Group, London, pp. 728-33.
Meachem, J.A. and Emont, N.C. (1989), "The interpersonal basis of everyday problem solving", in Sinnott, J.D. (Ed.), *Everyday Problem Solving: Theory and Applications*, Praeger, New York, NY, pp. 7-23.
Newell, A. and Simon, H.A. (1972), *Human Problem Solving*, Prentice-Hall, Englewood Cliffs, NJ.
Newell, A. and Simon, H.A. (1976), "Computer science as empirical inquiry: symbols and search", *Communications of the ACM*, Vol. 19 No. 3, pp. 113-26.
Perry, W.G. (1970), *Forms of Intellectual and Ethical Development in the College Years*; A Scheme, Holt, Rinehart & Winston, New York, NY.
Polanyi, M. (1967), *The Tacit Dimension*, Anchor Books, Garden City, NY.
Prince, M. and Hoyt, B. (2002), "Helping students make the transition from novice to expert problem-solvers", *32nd ASEE/IEEE Frontiers in Education Conference, November 6-9, 2002, Boston, MA*, Vol. 2, pp. F2A-7-11.
Quade, E.S. and Miser, H.J. (1985), "The context, nature, and use of systems analysis", in Miser, H.J. and Quade, E.S. (Eds), *Handbook of Systems Analysis: Overview of Uses, Procedures, Applications, and Practice*, North-Holland, New York, NY, pp. 1-32.
Reitman, W.R. (1965), *Cognition and Thought: An Information-Processing Approach*, Wiley, New York, NY.
Schon, D.A. (Ed.) (1991), *The Reflective Turn: Case Studies In and On Educational Practice*, Teachers College Press, New York, NY.
Simon, H.A. (1973), "Structure of ill structured problems", *Artificial Intelligence*, Vol. 4 Nos 3-4, pp. 181-201.
Sinnott, J.D. (1989), "A model for solution of ill-structured problems: implications for everyday and abstract problem solving", in Sinnott, J.D. (Ed.), *Everyday Problem Solving: Theory and Applications*, Praeger, New York, NY, pp. 73-99.
Smith, M.U. (1991), "A view from biology", in Smith, M.U. (Ed.), *Toward a Unified Theory of Problem Solving:Views from the Content Domains*, Lawrence Erlbaum, Hillsdale, NJ, pp. 1-19.
Stover, M.L. (2004), "The reference librarian as non–expert: a postmodern approach to expertise", *The Reference Librarian*, Nos 87/88, pp. 273-300.
Vygotsky, L.S. (1978), Edited by Cole, M., John-Steiner, V., Scribner, S. and Souberman, E. (Eds), *Mind in Society: The Development of Higher Psychological Processes*, Harvard University Press, Cambridge, MA.
Voss, J.F. and Post, T.A. (1988), "On the solving of ill-structured problems", in Chi, M.T.H., Glaser, R. and Farr, M.J. (Eds), *The Nature of Expertise*, Lawrence Erlbaum, Hillsdale, NJ, pp. 261-85.
Wetzstein, A. and Hacker, W. (2004), "Reflective verbalization improves solutions: the effects of question-based reflection in design problem solving", *Applied Cognitive Psychology*, Vol. 18 No. 2, pp. 145-56.
Wineburg, S.S. (1991), "Historical problem solving: a study of the cognitive processes used in the evaluation of documentary and pictorial evidence", *Journal of Educational Psychology*, Vol. 83 No. 1, pp. 73-87.
Xun, G.E. and Land, S.M. (2004), "A conceptual framework for scaffolding ill-structured problem-solving processes using question prompts and peer interactions", *Educational Technology Research and Development*, Vol. 52 No. 2, pp. 5-22.