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Information Retrieved from a Database and the Augmentation of Personal Knowledge

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Abstract **Objective:** To assess the degree to which information retrieved from a biomedical database can augment personal knowledge in addressing novel problems, and how the ability to retrieve information evolves over time.

Design: This longitudinal study comprised three assessments of two cohorts of medical students. The first assessment occurred just before student course experience in bacteriology, the second occurred just after the course, and the third occurred five months later. At each assessment, the students were initially given a set of bacteriology problems to solve using their personal knowledge only. Each student was then reassigned a sample of problems he or she had answered incorrectly, to work again with assistance from a database containing information about bacteria and bacteriologic concepts. The initial pass through the problems generated a "personal knowledge" score; the second pass generated a "database-assisted" score for each student at each assessment.

Results: Over two cohorts, students' personal knowledge scores were very low (~12%) at the first assessment. They rose substantially at the second assessment (~48%) but decreased six months later (~25%). By contrast, database-assisted scores rose linearly: from ~44% at the first assessment to ~57% at the second assessment, to ~75% at the third assessment.

Conclusion: The persistent increase in database-assisted scores, even when personal knowledge had attenuated, was the most remarkable finding of this study. While some of the increase may be attributed to artifacts of the design, the pattern seems to result from the retained ability to recognize problem-relevant information in a database even when it cannot be recalled.

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Databases are among the computer-based information resources supporting the educational and clinical needs of medical students and physicians. In today's environment, the learning and practice of medicine increasingly involve the integration of externally accessible information, from resources such as databases, with an individual's existing and emerging personal knowledge.¹ Available databases range from bibliographic resources such as MEDLINE²⁻⁷ to fact-and-text databases that provide information specific to a biomedical domain.⁸⁻¹¹ Our study at the intersection of medical informatics, information science, cognitive psychology, and education investigates the usefulness of a fact-and-text database as an adjunct to problem solving and learning in the basic biomedical sciences.

In 1986, our group developed INQUIRER, a computer database in bacteriology. Using INQUIRER, we were able to examine whether an educational intervention consisting of a biomedical database and faculty-developed problem sets affected students' proficiency for solving problems in the domain.^{10,11} We found a significant association between the extent of a student's use of the database for faculty-developed problem exercises in bacteriology and his or her score on a bacteriology posttest.¹² Overall, these results suggested that experience with a computer database in combination with course problem sets had a positive influence on learning.

These studies served to document the effect of a database on learning but did not elucidate its means of action. To extend our understanding of how database access might affect students' proficiency in problem solving, we developed a new set of studies that form the basis of this paper. In this work, we examined the degree to which information retrieved from a computer database augments a student's personal knowledge, potentially helping him or her to address a set of novel case problems. We performed this work in the context of an ongoing medical school curriculum. This allowed study of this phenomenon over time as students' personal knowledge changed as a consequence of scheduled course work. The existence of this knowledge augmentation process is intuitive. These studies offer a more "granular" analysis of the outcomes of this process so it can be understood more thoroughly.

Background

Memory and Problem Solving

Investigations of problem solving in medicine and

other knowledge-rich domains rest on the theory introduced by Newell and Simon.¹³ The theory views the problem solver as a processor of information found in three conceptually distinct "memories." Two of these are part of the personal memory of the human problem solver. One aspect of personal memory is short-term, with a rather limited native capacity of "seven plus or minus two" chunks of information.¹⁴ The other aspect of personal memory is long-term and is generally accepted to have unlimited capacity. The third memory outlined by Newell and Simon is the ubiquitous external memory, consisting of information external but accessible to the human problem solver. External memories are used to leverage the human information processor beyond the limitations of a person's internal cognitive resources.

The framework of problem solving posited by Newell and Simon envisions two focal cognitive processes that function together. One is an understanding or representation of the problem itself; the other is a search for the problem's solution.^{13,15} Understanding in knowledge-rich biomedical domains requires the individual to retrieve from long-term memory relevant schemas or previous knowledge regarding the type of problem requiring resolution. When looking for a solution, the problem solver searches first for a schema or script in long-term memory that applies to the novel situation he or she is facing. When relevant schemas for the problem cannot be retrieved from personal memory, the individual may engage in strategies to gather information from an array of external resources.^{16,17}

Personal knowledge or expertise, specific to a problem domain, has been demonstrated to be at the core of human ability to solve problems. The personal knowledge that experts can summon is generally extensive, well organized, and reflective of a deeper, more conceptual structure than that available to novices. The enriched cognitive knowledge structures of experts invariably foster more successful problem solving within a knowledge domain.¹⁸ Personal knowledge is essential for students, trainees, and physicians to be able to address diagnostic and management problems successfully in medicine.^{19,20} Studies illustrating the central role of personal knowledge in medical problem solving, across levels of training and experience, have been conducted in radiology,²¹ internal medicine,^{19,22} and dermatology.²³ Our work, in the spirit of the Newell and Simon theory, uses personal knowledge as a point of departure, but focuses specifically on how individuals can put an external memory resource to use when personal knowledge fails them.

Databases, Information Seeking, and Knowledge

This work also builds on numerous studies that have explored factors associated with the effective use of databases. Much of this research has focused on investigation of on-line bibliographic resources such as MEDLINE. Some of the studies have emphasized general characteristics of users, such as creativity, experience, or intelligence.²⁴⁻²⁶ Other studies have examined general facets of search behaviors, such as the number of commands, the number of search cycles, and the connect time required for the completion of search tasks.^{24,27-29} Haynes et al. have probed additional dimensions of MEDLINE searching, including the effect of feedback³⁰ and the impact of user fees,³¹ and have performed a comparative study of searches conducted by clinical end users and those conducted by librarians.³²

Facets of a user's personal knowledge explored in these studies of MEDLINE included knowledge of logical searching skills (e.g., use of Boolean operators and term specificity), knowledge for the operation of the search software (e.g., appropriate use of commands in GRATEFUL MED), and domain content expertise (e.g., librarians, novice clinicians, and experienced clinicians in this area). Overall, this work enhances the understanding of general user needs and characteristics of MEDLINE, the single most important bibliographic database for clinical practice and education.

Other research has explored the general impact of an individual's domain knowledge on personal retrievals of information from a database. Marchionini et al. conducted a series of four studies on how search experts and domain experts searched for information in full-text databases.³³ These investigations conducted in the domains of computer science, economics, and law, found that domain experts and search experts used different general information-seeking strategies. The search strategies of domain experts were based on content knowledge, while search expert strategies were grounded in the nature of the problem. The relationship of domain knowledge to database searching proficiency has also been demonstrated in studies by Linde and Bergstrom,³⁴ who posit domain knowledge as the basis for understanding information-seeking tasks. Linde and Bergstrom report an investigation in which subjects were given training on either the essential content in a database or the process of making logical combinations in a table search. Those given training on content exhibited superior performance as measured by level of error and efficiency in retrieving the information.

The reported research exploring databases and personal knowledge has defined success primarily in terms of search outcomes such as the proportion of relevant documents or information identified. A search that is successful in identifying problem-relevant information is clearly a necessary condition for solution of a complex problem when personal knowledge is inadequate. This success cannot also be a sufficient condition for problem solution, except in the rare circumstance where the search reveals information that literally contains the answer so no further interpretation by the person is necessary. In the general case, information retrieved from a database must be interpreted; it must be combined with personal knowledge through a process of recognition, understanding, and reasoning that can generate a solution. For this reason, our research goes beyond exploration of search outcomes to examine actual success in addressing problems, with assistance from a database, when it is known that personal knowledge alone is inadequate.

Research Questions

The specific research questions addressed in this study are:

1. Can a medical student, at a time when he or she is largely naive of the content in a domain, access and use information from a database to address identified gaps in his or her personal domain knowledge?
2. Soon after course experience in a domain, when personal knowledge may be expected to be relatively high, what changes occur in the student's ability to access and use information from a database to address gaps in personal domain knowledge?
3. Several months after course experience, what further changes occur in the ability to access and use information from a database to address gaps in personal domain knowledge?

Methods

Overview

We collected data from samples of medical students at the University of North Carolina at Chapel Hill (UNC-CH) via a series of assessments occurring on three occasions over nine months. Each assessment employed a "two-pass" protocol. In the first pass, we measured students' abilities to solve a set of prob-

lems using their personal knowledge only. In the second pass, we measured their ability to solve, with the assistance of information retrieved from the INQUIRER database, a subset of these problems for which their personal knowledge had been insufficient to generate a correct solution on the first pass. The study was carried out in the domain of bacteriology, which is taught in the first year of the undergraduate medical curriculum at the UNC-CH. The bacteriology course provided a context that anchored the investigation in time and allowed the study design to take advantage of learning that occurred through the course experience. Otherwise, the research study was separate from regular course activities and examinations. The research activities were carried out under identical conditions for two cohorts of medical students in successive years.

The INQUIRER Database

The INQUIRER database employed in this research was first introduced as a component of the bacteriology course in 1986.¹⁰ While the information in INQUIRER has been revised and expanded since that time, exploring the ease of updating the electronic form of the data, the structure of the database and the logic of its use have remained essentially unchanged. For the purposes of this research, INQUIRER represents an information resource focused on a particular biomedical domain, but, within that domain, a resource that provides access to a relatively broad and varied array of information for students in their first year of medical school. The extensiveness of the database for these targeted end users was important to the research because it helped ensure that the students would retrieve information via searching strategies, as opposed to browsing, in pursuit of problem-relevant information.

INQUIRER, as used in this research, is an interactive information retrieval program running on a Digital Equipment Corporation VAX 3200 computer (Digital Equipment Corporation, Maynard, MA), under VMS 4.7. Student users provide input to the program via screen forms and menus with numerous options, then view the retrieved data with full cursor control. Retrievals may be performed by using user-supplied keywords in Boolean combinations or by using several "browse" options requiring minimal user input. Searches may also be sequentially refined and rerun. Validity checking of user input is provided. For example, the program will not process a search containing a keyword that never occurs in the target field. The user is informed of this condition and is prompted to modify his or her search.

Information in the bacteriology INQUIRER database, as employed in this research, is divided into two files. The first is an ORGANISMS file containing descriptive information about microorganisms, in which each record corresponds to a single bacterium. The attributes of a bacterium are arranged in a logical sequence of fields. As used in this research, the ORGANISMS file contained 33 fields of information about 65 medically important bacteria. The fields embrace basic information such as gram stain and morphology, laboratory information such as tests used to identify the microorganism, and clinical information such as signs and symptoms of diseases caused by the microorganism. All data in INQUIRER are textual. Some fields, such as GRAMSTAIN, have a highly circumscribed set of possible contents; others, such as SIGNS and SYMPTOMS, contain paragraphs of free text. To facilitate free text searches, INQUIRER provides a scrolling menu of all searchable terms within each field. The second file is a CONCEPTS file, in which each record contains an elaboration of a particular concept of microbiology. The CONCEPTS file spans 33 concepts such as "transduction" and "virulence factors." Up to 15 records, each containing two or three sentences of free text, are devoted to the description of a single concept. The contents of the ORGANISMS and CONCEPTS files, while covering a substantial component of bacteriology, are circumscribed by the educational goals of the bacteriology course for first-year medical students.

Students at the UNC-CH used the INQUIRER database via microcomputers in their laboratory areas in the Medical Sciences Teaching Laboratories and in the Health Sciences Library. The computers connect to the VAX 3200 computer using an ethernet network available throughout the UNC-CH School of Medicine. This system sustained satisfactory response times—typically less than ten seconds to process a Boolean search—even when many users were logged on concurrently.

Subjects

Samples of UNC-CH medical students randomly selected from each class entering in the fall of 1990 and 1991 participated in the research. A student with any graduate degree or an undergraduate degree in microbiology was excluded from the study prior to selection of the samples. The samples were selected randomly with replacement from the students in the class remaining after these exclusionary criteria were met. For their participation, students received modest honoraria in the form of certificates available for book purchases at the campus bookstore. In the first cohort, 36 students participated on all three assess-

Figure 1 Schedule of the three research assessments in each cohort.

ment occasions and provided complete data for analysis in the studies reported here. Forty-three students participated to a similar extent in the second cohort.

Assessment Occasions

For each cohort, the assessments took place on three occasions. The first assessment took place in November of the first curricular year before the students had any exposure to the bacteriology course. The second assessment took place approximately three months later, two to three weeks after the bacteriology experience. The third assessment occurred five months later, in the first weeks of the second curricular year. During the period between the second and third assessments, students had no reason based in the curriculum to access INQUIRER. Figure 1 depicts the schedule of the three assessments in each cohort.

All first-year medical students, including the research subjects, were encouraged to use INQUIRER as a learning resource during the bacteriology course. The database could be used to support homework problem assignments, to identify "unknowns" in laboratory experiments, and to review for course examinations. To these ends, all students, including those participating in the research assessments, were given a user manual and oriented to INQUIRER in a 40-minute training session.

Assessment Procedures

In the first pass of the two-pass research procedure, personal knowledge was assessed with six written clinical case problems, each with three to six associated questions. (See the Appendix for an illustrative example.) Each of the questions called for a short-

answer response. Thirty-five minutes were allocated to the written exercise in the first pass. After completing the first pass, each subject presented his or her work to a member of the project team who identified incorrect and incomplete answers to the questions within each problem. With the aid of a selection algorithm, a sample of six "missed" questions (one from each clinical problem) was then identified for the student to attempt to answer again, this time with access to INQUIRER. Students were allowed 45 minutes for the second pass.

The assessments took place in a room equipped with computers for use in the second pass through the problem sets. Different sets of problems were used for each research assessment, but within each assessment occasion all students completed the same problem set. The assessment instruments used across the two research cohorts of students were identical.

The clinical case problems used in the assessments were representative of the range of topics covered in the students' bacteriology course. All problems used in the assessments were novel to the students. The six problems used in each of the three assessments were sampled randomly, after stratifying for content area, from a pool of 24 problems and then ordered randomly within each assessment. As seen in the Appendix, the questions embedded in each problem were of three general types. The first asked the student for a candidate set of bacteria that could cause the clinical manifestations described in the problem scenario. The second asked the student for the single most likely causal microorganism, often after the student was given some further information. The third focused on particular laboratory, clinical, or thera-

peutic characteristics of the sole causal bacterium. For all problems used in the research, the causative agent was represented in a record in the ORGANISMS file of INQUIRER.

By assigning on the second pass only questions that were answered incorrectly in the first pass, we sought to ensure that each student used INQUIRER to address questions for which his or her personal knowledge was inadequate. Since students typically missed several questions within each problem, the algorithm used to assign specific questions for the second pass was designed to minimize assignment of questions that required students to *look up only* information whose location in the database would be obvious. When the student had *not* correctly identified the causal bacterium, we assigned a question that sought some property or characteristic of the causal agent. (This required the student first to query the database to help identify the causal agent.) When the causal agent had been correctly identified, we assigned the "candidate set" question. The candidate question was assigned even when a student obtained partial credit for the question by, for example, correctly identifying one of several bacteria in the candidate set.

Variables and Scoring

The two-pass research protocol, as applied in this study, generated one independent and two dependent variables. The independent variable was the occasion of the assessment relative to the students' experience in the bacteriology course (see Fig. 1). The first dependent measure in our study was a "personal knowledge score." This score was the proportion of

questions, for all six problems, answered correctly on the first pass through the entire written assessment, using only personal knowledge. The second dependent measure, a "database-assisted score," was generated by the second pass through the set of six questions (one per problem) assigned to each student. The database-assisted score was the proportion of these assigned questions answered correctly by each student on the second pass. This score was a measure of the student's ability to answer correctly, with help from the INQUIRER database, a subset of the question he or she could not answer with personal knowledge alone.

As mentioned previously, an initial scoring of the assessments after the first pass occurred during the data collection session to identify questions that would be assigned for the second pass. An algorithm was used to guide selection of an incorrectly answered question within each problem. Formal scoring of the assessments used predefined answer keys to determine the correctness of responses in each of the two passes through the assessments. Two members of the research team reviewed and scored the students' responses. On rare occasions, a faculty member in bacteriology was consulted for any response that might be considered correct but that was not covered in the original answer keys. For both passes, all individual question responses within a problem were graded on a standard metric. Further data verification was conducted prior to statistical analysis of the database-assisted scores. This data verification helped ensure that database-assisted scores would not be biased upward by questions that might be trivial "look ups"

Table 1 ■

Bacteriology Personal Knowledge Scores (Pass 1) and Database-assisted Scores (Pass 2) by Cohort and Assessment Occasion*

	Assessment Occasion					
	November 1990		February 1991		August 1991	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
First study cohort (<i>n</i> = 36)						
Personal knowledge (Pass 1)	13.1	(8.3)	50.2	(10.6)	24.2	(11.5)
Database-assisted (Pass 2)	36.9	(22.1)	51.7	(30.2)	74.1	(22.8)
	November 1991		February 1992		August 1992	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
	Mean	(SD)	Mean	(SD)	Mean	(SD)
Second study cohort (<i>n</i> = 43)						
Personal knowledge (Pass 1)	12.3	(10.7)	45.6	(12.5)	26.7	(11.8)
Database-assisted (Pass 2)	50.0	(19.6)	64.2	(19.8)	76.6	(22.1)

*Scores are expressed as percentages.

from the database given an individual student's responses on the first pass.

First, we reviewed all student responses to eliminate questions that would be relatively easy to answer using INQUIRER on the second pass. This might occur, if, on this second pass through the assessment, the assigned question sought a property of a bacterium whose identity the student knew from a previous correct response in the first pass through the assessment. Second, we opted to delete any question assigned on the second pass for which a student had already received partial credit in the first pass. While this screening did reduce the number of questions contributing to the database-assisted scores, it ensured a homogeneity of task that was important to the validity of the findings.

Analysis

The two dependent variables, personal knowledge and database-assisted scores, were measured across the three assessment occasions of the independent variable. The data were analyzed with repeated-measures multivariate analysis of variance (MANOVA) over the three levels of time with associated univariate analyses.³⁵ Data for each cohort were analyzed separately. Trends across the three occasions were examined to assess the nature of any evolution of the personal knowledge and database-assisted scores over time.

Results

The means and standard deviations of the personal knowledge (Pass 1) and database-assisted (Pass 2) scores for each assessment are presented in Table 1. When interpreting these results, it is important to note that scores of the same type can be compared across occasions. At each assessment occasion, however, the two different score types cannot be directly compared with each other. The database-assisted scores are dependent on gaps in subjects' personal knowledge. They are based on subsets of the questions used to determine the personal knowledge scores.

For both cohorts, these analyses revealed significant differences in both the personal knowledge (Pass 1) and the database-assisted (Pass 2) scores across the three occasions of the assessments ($F(4,32) = 129.95$, $p < 0.0001$ for the first cohort; $F(4,39) = 70.58$, $p < 0.0001$ for the second cohort). For the personal knowledge scores, linear and quadratic trends were found to be significant in both cohorts. For the da-

tabase-assisted scores, only the linear trend for this dependent variable was significant. For all assessments and both cohorts, the database-assisted scores demonstrated substantially greater student-to-student variability than did the personal knowledge scores.

Results for Each Research Question

1. *Can a medical student, at a time when he or she is largely naive of the content in a domain, access and use information from a database to address identified gaps in his or her personal domain knowledge?*

At the first of the three assessments, the personal knowledge scores were low, verifying that students were naive of the domain content. Students in the first and second cohorts were able to respond correctly to only 13.1% and 12.3% of the questions in the first assessment, respectively. The mean database-assisted scores for the initial assessment (36.9% for Cohort 1, 50.0% for Cohort 2) suggest that, prior to any formal instruction in a domain and when personal domain-knowledge was low, students were able to answer a substantial fraction of initially missed questions when assisted by retrieval of relevant information from the INQUIRER database.

2. *Soon after course experience in a domain, when personal knowledge may be expected to be relatively high, what changes occur in the student's ability to access and use information from a database to address gaps in personal domain knowledge?*

We observed the expected rise in personal knowledge scores from the first assessment (prior to bacteriology instruction) to the second assessment (immediately following the microbiology course segment in bacteriology). As shown in Table 1, the mean scores rose to 50.2% for Cohort 1 and to 45.6% for Cohort 2. The mean database-assisted scores also rose from the first assessment, to 51.7% and 64.2% for the first and second cohorts, respectively. The ability to access information from a database to address gaps in personal knowledge rises in a linear fashion that appears to parallel the increase in personal domain knowledge.

3. *Several months after course experience, what further changes occur in the ability to access and use information from a database to address gaps in personal domain knowledge?*

At the third and final assessment for both cohorts, mean personal knowledge, as measured in this study,

had diminished substantially to 24.2% in the first cohort and to 26.7% in the second cohort. However, database-assisted performance to accommodate gaps in personal knowledge continued to increase. These database-assisted scores in the third assessment occasion were 74.1% for the first cohort and 76.6% for the second.

Discussion

The trends in personal knowledge and database-assisted scores are each depicted in Figure 2. Since the two cohorts displayed the same temporal trends, we pooled results from each score type across the two cohorts for display in the figure. The parabolic trend for personal knowledge, progressing from very low to moderate and then declining, was statistically significant in both cohorts. These results are in accordance with findings of other studies documenting limited long-term retention of basic science material.³⁶ The moderate scores for the second assessment—on the order of 50%—attest to the difficulty subjects had responding to these short-answer case problems when they had no resources except personal knowledge with which to address them.

The database-assisted scores were modest, but perhaps higher than may be expected, for the first assessment in each domain. It appears that students, with minimal training and personal knowledge of the domain, can use a structured information resource that is logically designed and that offers cues to guide its use. This finding also suggests that students who are halfway through their first year of medical school have a level of biomedical literacy that enables them to identify pertinent "givens" in a problem and to translate them into Boolean search statements that retrieve some relevant information. Even when his or her search may have been successful in retrieving the most useful information in the database, a student may still fail to answer a question because he or she lacks the personal knowledge necessary to interpret what was retrieved and to reason from this to construct a correct response. These students also may not have been able to distinguish relevant and irrelevant material within the totality of what they retrieved.

In the interval between the first and second assessments, the students engaged in the study of bacteriology as part of the regular medical curriculum and had the opportunity to use INQUIRER in support of this work. The rise in database-assisted scores from the first assessment to the second assessment paralleled the expected rise in personal knowledge scores. Even when the students did not have the specific

Figure 2 Temporal trends of personal knowledge scores (left) and database-assisted scores (right) with the cohorts pooled ($n = 79$). Note: The two score types are not directly comparable.

personal knowledge sufficient to answer a question, their greater general knowledge of the domain would help them frame effective database queries because the terms used in the problem and in the database would be more meaningful. Greater success in searching would also result from increased familiarity with the content, structure, and operation of the database. Finally, the students' greater personal knowledge would help them recognize and interpret the problem-relevant information they retrieve via their database queries. This result is consonant with findings obtained by Marchionini et al.³³ and Linde and Bergstrom,³⁴ in which domain or content knowledge was found to have an effect on searches for information.

The personal knowledge and database-assisted scores did not follow parallel trends from the second assessment to the third. In both cohorts, database-assisted scores increased from the second assessment to the third assessment, while personal knowledge scores declined significantly. Our general expectation was that database-assisted scores for the third assessment occasion would follow the trend in personal knowledge scores and decrease—though perhaps to a lesser extent than did the personal knowledge scores. The observed increase in database-assisted scores occurred in the absence of any curricular motivation to use INQUIRER in the five-month interval between the second and third assessments, much of which was a summer vacation. Therefore, additional accumulated experience with the database cannot be a cause of this trend. Other curricular experience with database searching, specifically MEDLINE, also cannot be a reason for this trend. In the UNC-CH cur-

riculum, MEDLINE searching is first required for the second-year course in epidemiology. The scheduled introduction to MEDLINE for the second-year epidemiology students, a 20-minute demonstration in a large lecture setting, occurred *after* the third assessment occasions of the research reported here.

Probing the Trend in Database-assisted Scores

To explain the temporal trends from the second to third assessments, we first explored possible artifacts of the experimental design and analysis methods. The occurrence of the same trend in both cohorts would appear to rule out idiosyncrasies of the curriculum or the students within a particular year. It is also not likely that the problems used in the third assessment were easier as a set than those used in the second assessment, because of the random assignment of problems to sets and because personal knowledge scores decreased so precipitously in the third assessment.

Student maturation may be a factor that was not fully controlled in this study. The increased database-assisted scores for the third assessment could be attributed in part to a personal change in the students from the spring of the first year of medical school to the beginning of the second year. One component of this maturation is cognitive and consists of the development of enriched schemas for the knowledge base in the biomedical sciences garnered from all their courses in the first year of medical school. Another element of this maturation is more affective or attitudinal. During the third assessment, the research team observed a focus and no-nonsense efficiency in the students' use of INQUIRER, which was not seen on the two previous occasions. These students had been successful in a major educational challenge—passing the first year of medical school—and entered the second year with greater confidence for any task, particularly one in which they had been at least partially successful several months earlier.

Another artifact potentially affecting the results involves the dependence of the questions assigned for the second pass on the questions missed in the first pass. This dependence would artificially inflate the database-assisted scores for the third assessment if the questions varied substantially in intrinsic difficulty. Since the easiest questions within each set may be answered correctly in the first pass, the mean difficulty of the questions available to assign for the second pass may be greater when there are fewer questions to assign; that is, when personal knowledge scores are higher. Since personal knowledge scores were higher for the second assessment than

for the third, this effect may artificially inflate the database-assisted scores for the third assessment. This artifact is a consequence of the task dependencies built into the research design. The algorithm used in the assignment of questions for the second pass and the two screens subsequently applied in scoring work to minimize this effect but cannot guarantee its elimination. This potential effect would assume, in part, the direct equivalence of the "easy to difficult" continuum for the tasks in the personal knowledge and the database-assisted portions of the assessments. Conceptually, this direct equivalence of task is not supported by the elucidation of long-term personal memory and external memories in the theoretical or empirical work by Newell and Simon or that by other investigators of human cognition.

On balance, student maturation and, possibly, task dependence must be considered potential factors biasing the database-assisted scores upward for the third assessment. Even with these factors taken into account as the reason why the database-assisted scores might have increased, it is still necessary to account for why these scores did not decrease. Therefore, we sought a mechanism to account for database-assisted scores that would at least remain stable from the second to third assessments. We hypothesized that an important aspect of personal knowledge not tapped by our assessment exercises was more persistent, and present to a greater extent in the third assessment, than was the aspect of personal knowledge that was tapped by the exercises. It is possible that a student who was not able to recall sufficient personal knowledge to *construct* a short-answer written response on the first pass through the problems still had sufficient personal knowledge to enable him or her to undertake successful database searches and to *recognize* problem-relevant information when, on the second pass, he or she saw it in the database.

To explore this possibility, we conducted a collateral experiment. We administered a 22-item multiple-choice assessment to 38 students of the second cohort—*nine* months after their course experience. The content of this multiple-choice assessment paralleled the content of the first research assessment taken 14 months earlier and for which the students had never received any direct feedback regarding correct responses or individual performance. The mean score for this assessment was 53%, after correcting the multiple-choice scores for chance. This is significantly higher than are the personal knowledge scores for these same students five months after their course experience.

This collateral experiment suggests that the ability to recognize pertinent information in a domain once learned persists for a longer time than does the ability to recall and express knowledge as required on the short-answer questions used in the research assessments in our study. The students appear to have developed a better understanding (in other words, more elaborated schemas) of problem-related knowledge in bacteriology that was sustained over time. With the presentation of novel bacteriology problems on the third assessment occasion, an arousal or cueing of personal knowledge in memory may have occurred, at least partially, during the first pass through the assessment. This partially cued personal knowledge or schema may have combined with the external reinforcement of the organization and the content of the domain, as represented in the database, allowing a student to recall details of problem-related domain content that he or she may not have been able to generate without information from the database. If this persistent ability to recognize problem-relevant information in INQUIRER, even when a student could not produce this information from personal memory, were accompanied by an equally persistent ability to use the database, this could account for database-assisted scores that did not attenuate from the second to the third assessments.

Although we plan further research to elucidate this phenomenon, we believe that the "persistent recognition" aspect of knowledge in a domain once learned combined with a potential maturation effect to explain the lack of attenuation of the database-assisted scores from the second to third assessments. It is possible that the observed increases in database-assisted scores resulted from student maturation and possible task dependency effects that our experimental design did not control.

Conclusions

Our findings relating to the attenuation of personal knowledge are not new. What are new and potentially significant are the results that estimate the magnitude of personal knowledge augmentation possible with a database and the results that support the persistent beneficial effect of a computer-based information resource in problem-solving tasks. These findings, reflected in the mean scores of each cohort over time, suggest that a database as an external memory resource can empower an individual to solve problems that he or she could not solve with personal knowledge alone. The findings also suggest that the use of a database to support study in a domain can have enduring effects. We cannot yet fully explain

this phenomenon, but a primary factor appears to be persistent schemas of mastered knowledge in long-term memory that offer an individual the ability to *recognize* useful information that was once learned when it is presented in a database, even when he or she is unable to *recall and express* it.

Outside of a research setting, the use of personal knowledge and of information from external resources does not occur sequentially as it did in the design used in this research. Instead, in a myriad of instances, personal knowledge and information from external resources are employed in a dynamic, synergistic interplay. The phenomenon of knowledge augmentation through access to external resources can leverage the individual well beyond his or her personal cognitive resources.

The apparent ability to recognize relevant information long after domain content can be readily recalled and expressed may be of direct relevance to the continuing education of physicians as well as the education of medical students. Covell and others^{37,38} have noted the extensive information needs of physicians; a majority of these needs are not readily addressed by existing information resources. The results of our study may offer a strong case for augmenting medical education programs at all levels with readily accessible, focused electronic information resources that support the subject areas of those programs.

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APPENDIX

Sample Bacteriology Problem

A 30-year-old man presented to a local medical center complaining of mild pains in facial muscles and jaw muscles, slight difficulty in swallowing, stiffness of the neck, headaches, and backache.

1. List two organisms that might produce symptoms of this type.
- It was further determined that the patient had a narcotic addiction and subsequent examination revealed a localized wound on the inner left forearm. Microscopic examination of a Gram-stained smear of exudate from the wound revealed the presence of Gram-positive bacilli, some of which had spherical terminal spores. (Please do not change your answers to part 1 above.)*
2. With what disease are these further findings most consistent?
 3. Given this information, how should appropriately inoculated media be incubated in order to culture the organism seen in the Gram stain so that a positive diagnosis can be made?
 4. What treatment regimen would be appropriate for this condition?