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Metacognition in Adult Learning of Problem Solving Skills:   
A Literature Review

I have been involved in teaching computer programming to adults for the past several decades, first in industry (in-house education for Boeing and then train-the-trainer for Microsoft) and more recently in academia (North Seattle Community College). The students I teach are generally highly interested and engaged in the topic, since their future, either employment or admittance into a given academic program, depends on their success in the class. Even with this relatively high degree of motivation, student achievement varies quite greatly. Anecdotal evidence doesn’t suggest that this variation in student achievement is directly attributable to differences in native intelligence. But, there does seem to be a “something” that enables some students to address programming problems more successfully than others. The question then arises: What is this “something”? With the follow-on queries of: Is it innate? Or can it be developed? Can its development be fostered in adult learners? and: If so, how?

In other words, the specific research question that I have involves the development in adult learners of skills in creating computer programs to solve novel problems; essentially, this is the development of computer programming problem solving skills in adult learners.

There is relatively little in the literature about the specific topic of adult problem solving skills. In fact, there is actually relatively little about adult learners in the literature, with the exception of reasonably sized body of work in second language acquisition (SLA). This adult SLA work often compares language acquisition in children and adults. Two overviews of adult SLA theory are included in this literature review

There is, however, a significant body of research literature examining the development of problem solving skills in school-age children and young people. From this extensive base, three articles are included here: two looking at mathematical problem solving in elementary school children, and one specifically targeting programming instruction in high school student.

A synthesis of these two bodies of literature may provide a reasonable basis for the proposed research work. The studies on the development of problem solving skills in children will provide the basic conceptual framework for the research, with this framework tempered by the differences in adult and child learning drawn from the SLA literature.

What follows is a brief recap of some potentially relevant literature. For each article, a summary of the content is given, followed by a brief paragraph situating the article within the theoretical frameworks we have studied and the potential application of the article to the suggested research activity.

Examples from Second Language Acquisition

Swaffer (1989) provides an overview of second language learning in adults. The previous years had experiences a major shift in emphasis in adult language education from *langue* to *parole*, to use Saussure’s terminology, that is, from language-centric instruction focusing on forms and rules to usage–centric instruction focusing on communicative need. Related to this is a fundamental change in perception of adult SLA.

It had long been noted that adults do not seem to be able to attain the same levels of proficiency as children, particularly in terms of pronunciation, but generally in most all aspects of grammar. Historically, this had caused adult SLA to be viewed as “deficient” in some way and therefore not a reasonable target for primary study. In the newer view, adult SLA is not defective, but simply different, in fact, vastly different.

Young children seem to be able to acquire language effortlessly, by mere exposure to circumstances with communicative need in the language. Taking this as the normative mode for language acquisition led to the grammar-free immersion programs for SLA of the 60s. In fact, I have a French 101 textbook from the period which contains exactly one word of English, in a footnote.

While young children implicitly learn language, adults, and older children for that matter, do better with explicit instruction which can build on their cognitive skills. As an example, most European languages have multiple forms for the second person subject pronoun whose usage varies based on number and formality. For example: *tu* and *vous* in French; *du*, *ihr*, and *Sie* in German; *tú*, *vosotros*, *Usted*, and *Ustedes* in Spanish; where contemporary English has only one form, *you*. Older learners seem to benefit from explicit instruction about these forms and their differences, where young children seem to acquire / apprehend these distinctions implicitly.

From Swaffer’s overview, one can see that the cognitive skills should be applied to / leveraged in adult learners. Moreover, the shift from *langue* to *parole* signals recognition of contextualized education as being more productive than paradigmatic memorization; students, particularly adults, learn better when the information is contextualized and its application is known.

Fraser (1992) also provides overview of adult SLA, focusing on three related theories of Krashen, Anderson, and Bialystok.

A decade earlier Krashen had proposed the distinction between language *learning*, a conscious process with an external focus, and language *acquisition*, an unconscious process with an internal focus. Based on the earlier view that “true” SLA is the effortless intake of language by young children, Krashen considered acquisition is the goal of second language instruction. To prompt this unconscious, internal process of language acquisition, Krashen promoted language instruction where student interaction in the language was at level “*i+1*”, just beyond the current level of the student, which he termed “*i*".

Anderson also characterized language knowledge as a two-prong affair. For Anderson, the distinction was between declarative (know *that*) and procedural (know *how*) knowledge. In terms of language, speaking is more procedural, while reading is more declarative. Anderson also posits that knowledge can move from declarative to procedural by being activated. Anderson’s view of the process of activating the declarative knowledge is not covered in Fraser’s overview. For this, Fraser turns to Bialystok.

Bialystok examines bilingualism and cognition. Bialystok’s view is that analysis of language knowledge leads to activation of that knowledge. As a concrete example, SLA often involves the initial memorization of stock phrases and sentences. These are chunks of language, which can be used in conversation to fill communicative need. However, they are unanalyzed, so they may well be misapplied. For example, the chunk “I would like to buy some *X*.” is generally useful. It works for both count and non-count nouns, and so can be productively combined with a number of objects: “milk”, “bananas”, “pork”. Without knowledge of the underlying grammar, though, it can be misapplied: “I would like to buy some *two chickens*.” As language learning progresses, these chunks undergo analysis which activates that knowledge. This opens the possibility of broader applicability of the contextual structure. As a second example, in Spanish, “Me gusta *X*.” is the chunk for “I like *X*.” “Me gusta la música.” (I like the music.), “Me gusta la comida.” (I like the food.), but it cannot be applied to plural nouns. “Me gusta*n* las enchiladas.” rather than “Me gusta las enchiladas.” because the apparent object (*X*) is actually the subject of the sentence, “*X* is/are pleasing to me.” This “backwards” structure appears in a number of affective constructions in Spanish. So, once this familiar chunk is analyzed, that activated knowledge is relatively broadly applicable.

From Fraser’s overview, one can see Krashen’s view of instruction at level *i+1* roughly parallels Vygotsky’s zone of proximal development (1978). Even though the application and theoretical bases are somewhat distinct, a close informal parallelism can be drawn. Moreover, the Anderson / Bialystok idea of analysis / activation leading to fluency can be understood as a reformation of internal structures to encompass new cognitive material. This is essentially parallel to Piagetian accommodation (Brainerd 1978). Alternately, this idea echoes the observation by Bransford et al. (2000) that expert knowledge is structured differently than novice knowledge and that this restructuring facilitates recall, application and transfer. These ideas also underscore the need for sufficient knowledge to be available before transfer can take place (Bransford, et al. 2000).

Examples from Mathematics

Jackson, et al (2013) examined middle-school math classes, all of which had experience with a three-part instructional format: initial large-group exposition, small group exploration, and large-group recap discussion. They found that certain aspects of the initial presentation had a marked effect on the success of the educational activity, as assessed through the kind, amount, and quality of student participation in the large-group recap. Specifically, features they found that led to successful initial large-group presentation are: active student participation / interaction, highlighting the problem context, clarifying the underlying mathematical concepts, and establishing a common language for working the problem.

The features of successful set-up amount to metacognitive scaffolding for the task. Similar finding are suggested by Kuhn and Pearsall (1998) where metacognitive descriptive power is positively associated with successful task completion. With older learners, it should be possible to provide metastrategic training so that they could foster their own successful problem set-up, as suggested by Kuhn (2000).

Similarly, Desoete, Roeyers, and De Clercq (2003) examined the effects of different kinds of off-line instruction on the abilities of third-graders in solving mathematical problems. They were specifically interested in transfer of skills between topic areas. Over the course of two weeks, small groups of about 10 students each were given instructional intervention in five 50-minute periods in one form of instructional treatment. The five forms of intervention are: metacognitive instruction, cognitive instruction, motivational instruction, quantitative/relational instruction, and spelling instruction (control group). The two groups with cognitive and with metacognitive instruction had a significant increase in performance between pre- and post-treatment assessments, where no significant change was seen in the other three treatment groups. Six weeks after the end of the interventions, a follow-on assessment showed that the group which had received metacognitive instruction continued to have a significant increase in performance, where the group which had received cognitive instruction showed no significant difference from the other three groups at this later assessment.

One of the most interesting aspects of the Desoete et al. study is that the instruction in each of the five types of intervention was not directly related to the mathematical problem solving being assessed. So, these findings are an indication of the utility of metacognition as the basis for transfer. As noted in *How People Learn* (Bransford, et al, 2000), measures of transfer play an important role in the assessment of the quality of learning experiences.

Example from Programming

The one programming study that seems applicable was carried out by Husic, Linn, and Sloane (1989). They examined instructional practices in 16 high-school classes teaching programming in Pascal: 8 intro classes and 8 advanced placement (AP) classes. The instructional content of the two sets of classes was quite uniform within each set. In the intro classes, the instructional focus was introduction to the Pascal language and to programming fundamentals; in the AP classes, the content was targeted to the AP placement exams. They found that students in AP classes do better with more leeway, where students in intro classes need more structure to succeed. For both sets of classes, new knowledge is successfully applied given sufficient, appropriate scaffolding.

At first blush, there seems to be little that can be directly drawn from this study to support the proposed research. Further reflection leads to the notion that independent work seems to require a sufficient body of background knowledge, as shown by the greater productivity of the AP classes in low guidance situations where the introductory classes displayed more productivity in circumstances with a higher degree of supervision. This may suggest that this metacognitive work will prove to be more highly leveraged in intermediate level programming classes, rather than introductory.

Implications for Research

Several consistent threads can be collected from these articles that may be directly applied to the proposed research.

The “something” shared by successful programmers seems to be metacognitive in nature. The problem solving tasks are all enhanced by increased metacognitive resources. Since those metacognitive resourced do not need to be directly related to immediate topic (Desoete, Roeyers, and De Clercq, 2003), this success in an example of transfer. As described by Bransford, et al (2000) transfer requires sufficient topic knowledge which is not too highly contextualized. Their discussion continues by saying transfer is built on understanding of the material rather than simple rote memorization of facts.

The task of computer programming in the workplace involves solving novel problems. This stands in distinction to many engineering disciplines where the common task is the adaptation of proven techniques and technologies to new circumstances. That is, engineering often involves the adaptation of a known solution. In software development, on the other hand, typically the task is to create a module which doesn’t exist, that is, which hasn’t been written before. In this respect, it can be viewed as a more creative endeavor than some other areas of engineering and technology. Were the software solution to already exist, it would be, more often than not, far more cost effective to buy the completed solution and adapt it to the current need, rather than devote expensive employee resources to develop it from scratch. In this light, one can say that the primary task of programming involves problem solving, and since the situations shall typically be novel, these will be situations where transfer will be applicable and valuable.

This amounts to adaptive expertise as described by Bransford et al. (2000). As they point out, a restructuring of the cognitive material is found in expert understanding. In fact, the underlying structure of knowledge can inhibit or enhance the use and application of that knowledge (Swaffer, 1989). The underlying conceptual framework then can have a profound effect on the success or failure in the task at hand.

As Kuhn (2000) points out, metastrategic development is not the case of discarding incorrect strategies, but a change in the choice of strategy. Thus negative transfer, as shown in the examples of Bransford, et al. (2000), could be linked to a limited palette of strategies, as much as to priming, as demonstrated by the authors.

So, this research could be centered in capturing the mental processes that are employed by experts and knowledgeable novices in solving elementary and intermediate difficulty programming problems. This information could be collected by recording a “think-aloud” procedure for these tasks. The collected data will likely be a combination of cognitive and metacognitive processes. Examining the cognitive material used by the experts and comparing it to that which is used by the novices could help illuminate knowledge and techniques that may not be reasonably presented in the current curriculum, which would be an interesting by-product / side benefit. The more important data would be the processing of this cognitive material, the metacognition.

The expectation is that while the experts and novices may employ a wide set of cognitive processes, there may be little or no pattern discernable to distinguish between the two groups. Novice structuring of knowledge may be uniform or widely diverging as shown by the metacognitive processes, depending on the congruity of the framework(s) developed by the novices based on the surface features selected as salient. On the other hand, the current expectation is that the metacognitive processes among the experts will be rather uniform due to the congruent restructuring of the underlying conceptual framework, the framework that distinguishes expert knowledge and greater faculty in application. In fact, the hope is that the topography of this restructured conceptual framework may be discernable from these observed metacognitive processes. Follow-on work could examine what kinds of prompting may foster metacognitive “broadening/restructuring” in the novice, and hence, greater transfer and greater problem solving success.

**References and Annotated Bibliography**

Brainerd, C. (1978). *Piaget’s Theory of Intelligence*. Englewood Cliffs, NJ: Prentice-Hall.

Children think in a manner that is qualitatively different than adults. Piaget’s theory is based around stages of development that are qualitatively distinct and develop in a given order. Cognitive growth can be characterized as change which is either quantitative (assimilation, where data is molded to conform to current cognitive structures) or qualitative (accommodation, where cognitive structures are reorganized to admit new data forms).

Bransford, J.D., Brown, A.L., Cocking, R.R. (2000). *How People Learn: Brain, Mind, Experience, and School*. Washington D.C.: National Academy Press.

Chapter 2: How Experts Differ from Novices. (31-50).  
Experts and knowledgeable novices may command similar data about a subject. In fact, the novice even may have quicker recall for the information. The qualitative difference, the essential difference, is in the organization of the data. Experts categorize knowledge into “meaningful” chunks, based on *underlying* similarities, allowing greater abstraction and potential transfer. Novices also categorize information into “meaningful” chunks; however, the novice grouping is based in *surface* similarities. This allows for rapid classification of information, but does not necessarily lead to expert performance, namely enhanced problem solving or transfer.

Chapter 3: Learning and Transfer. (51-78).  
Bransford notes that positive transfer has been identified with education, in distinction to training. Key characteristics of learning and transfer: 1) sufficient knowledge, 2) knowledge not overly contextualized, 3) transfer as the process of application, not the end product, 4) new learning is transfer which builds upon previous knowledge. Mastery of the initial topic fosters transfer of those skills. The goal, therefore, should be understanding, rather than memorization. This takes time, since it involves the internalization of the material. Metacognitive can scaffold this internalization.

Desoete, A., Roeyers, H., De Clercq, A. (2003). Can Offline Metacognition Enhance Mathematical Problem Solving? *Journal of Educational Psychology 95(1)*. 188-200.

Five groups of third graders are given 5 different types of “enhancing instruction” for mathematical problem solving: cognitive instruction, metacognitive instruction, motivational instruction, quantitative-relational instruction, spelling instruction (control group). Instructive sessions were 5 sessions within 2 weeks, 50 minutes per session. Cognitive and metacognitive instruction led to the best results. Six weeks after the study, metacognitive group alone showed increase in assessed skills. Similar results with transfer assessment.

Flavell, J.H. (1979). Metacognition and Cognitive Monitoring: A New Area for Cognitive-Developmental Inquiry. *American Psychologist 34(10)*, 906-911.

This is an early description of metacognition as a phenomenon that is lacking in younger children, but then develops in older children and adults. He describes four types of metacognition: metacognitive knowledge (knowledge about knowing about people, tasks, and strategies), metacognitive experiences (awareness of metacognition), goals, and strategies. The discussion focuses on metacognitive knowledge and metacognitive experiences.

Fraser, C.A. (1992). The Role of Knowledge about the L2 Code in Adult Second Language Acquisition: A Review of Theories and Research. *TESL Canada Journal/Revue TESL du Canada. 9(2)*. 50-71.

This article starts with the distinction between "know that" and "know how". Karshen’s hypothesis is that learning is a conscious, external process where acquisition was a sub-conscious, internal process and that usable skill in L2 is associated with acquisition, rather than learning. (Krashen: 1981, *Second Language Acquisition and Second Language Learning*) Krashen’s ideas also include acquisition at *i+1*, just beyond what is has been acquired.

Anderson examines L2 in terms of cognitive psychology. Initial learning is propositional / declarative in nature; through application / performance, this knowledge becomes activated and and the proceduralized knowledge is restructured into production sets. Proceduralization leads to activation of declarative knowledge. Speaking uses procedural knowledge, where writing can take advantage of declarative.

Bialystok in studying bilingualism and cognition, posits analysis of knowledge and cognitive control as the mechanism of operationalizing. Cognitive control is selecting better models; analysis of knowledge is restructuring a la expertise. In SLA, unanalyzed segments of language (initial formulas and chunks) are later analyzed and put into a larger contextual structure. However, the unanalyzed chunks can still be productively used, but only within limited contents.

Husic, F., Linn, M., Sloane, K. (1989). Adapting Instruction to the Cognitive Demands of Learning to Program. *Journal of Educational Psychology, 81(4)*. 570-583.

Thus study examines Pascal programming: 8 intro classes and 8 AP classes. They posit a chain of cognitive development: 1) syntactic and semantic primitives, 2) design skills to use language features, 3) generalizable problem solving skills. The intro classes focus on the first link in the chain, and a bit of the second link. AP classes, on the other hand, focus more on the second and third links in the chain. Class contents was quite uniform, since the intro classes must cover programming fundamentals and language syntax (and semantics) as a matter of course; AP testing constrains educational outcomes criteria for the AP classes. Math prereq uniformaly. Most AP have a programming prereq as well. Teaching strategies differ. AP flourish with more liberty. Transfer is good in both groups, given appropriate educational support.

Jackson, K., Garrison, A., Wilson, J., Gibbons, L., & Shahan, E. (2013). Exploring relationships between setting up complex tasks and opportunities to learn in concluding whole-class discussions in middle-grades mathematics instruction. *Journal for Research in Mathematics Education, 44(4)*, 646-682.

This study examines middle-school math classes. All using a three part teaching format that has been introduced early: initial exposition, small group work, all-class recap and discussion. The specific problem was the first (graphing and evaluation) problem with a non-zero y-intercept: Dancing for Dollars. Framing in the setup shown to be very important: contextual information (rationale for problem), mathematical ideas / relationships, common language for the problem, consistent cognitive demand. Study provides positive correlation between high quality set-up (as measured by these criteria) and student achievement (as measured by student linking, student providing, and academic rigor of the discussion, all of which are assessed in the all-class follow-up discussion.

Kuhn, D. (2000). Metacognitive Development. *Current Directions in Psychological Science, 9(5)*. 178-181.

In this brief piece, Kuhn recounts the current views around metacognition and its development. Based on the distinction between declarative and procedural knowledge, she proposes different kinds of metacognitive knowledge: metastrategic knowing (knowing about procedural knowledge) and metacognitive knowing (knowing about declarative knowledge). This leads to the hypothesis that development is adapting strategic application based on metacognitive processing of results. There is a further research in metacognition and possible subsequent application in educational process.

Kuhn, D., Pearsall, S. (1998). Relations between Metastrategic Knowledge and Strategic Performance. *Cognitive Development. 13(2)*. 227-247.

This study examines 47 5th graders in a problem solving tasks specifically examining the factors that will affect speed of a toy sail boat: water depth, sail size, weight (force) applied, etc.. The analysis was microgenetic in nature. They examined a wider view of metacognition, more than just recall of metacognitive material, specifically two forms of metacognitive knowledge: knowledge of task objectives and knowledge of strategies. Strategic mastery lags (is dependent on?) particular levels of metastrategic understanding. They found bidirectional linking between the two. Metacognitive knowledge was assessed examining explanations of the task by the subjects to other 5th graders.

Schwab, J.J. (1978). Education and the Structure of the Disciplines. In Schwabb, J.J., Westbury, I, Wilkof, N.J. (eds.) *Science, Curriculum, and Liberal Education: Selected Essays* (229-272). Chicago: University of Chicago Press.

This essay discusses the centrality of structure in understanding. It starts by examining the ideas of *knowledge* and *truth*, exposing both of them as non-absolute. Structure imparts meaning. Even “unambiguous” declarative sentences change implication based on context. It continues by discussion structure as related to the development of skills. It provides rich examples and counter-examples of differences in underlying mental structure of statements with surface similarities. It continues by asking “who knows” the structure of a subject; in fact, two questions, “*who* knows?” and “who *knows*?” leading to the notion that the structure of any subject may not be absolute. It then highlights the notion that underlying structure strongly affects which can be apprehended. So, structure, particularly an unexamined underlying structure, can “blind” us to truths.

Swaffer, J.K. (1989). Competing Paradigms in Adult Language Acquisition. *The Modern Language Journal. 73(3)*. 301-314.

This is an overview of various mental models of adult language acquisition. The change of the previous 20 years can be characterized as a shift from *langue* to *parole*, the idealized norm of a speech community and daily communicative usage laden with pragmatics. Alternately, this can be characterized as a shift from a language-centric to a learner-centric approach. Thus, speaker cognition is recognized as a major facet of language production and language acquisition. There is a contemporaneous change in the view of the adult learner. Historically, Chomskian ideas such as the language-acquisition device and universal grammar held that true language acquisition can only happen during a critical period. After that, language learning was always partial / defective, and therefore not worthy of study. The paradigm shift in language instruction to learner-centered / language in context opened the door to study and acknowledge the contribution of adult cognition in SLA. For example, how do we *understand* the underlying difference between "John is eager to please" and "John is easy to please" when there is such strong surface similarity? It continues noting that there are many (potential) applications of this shift ... but that these are often stymied by lack of change in assessment.

Vygotsky, L.S., (1978). Interaction between Learning and Development. In Cole, M., John-Steiner, V., Schriben, S., Souberman, E. (eds), *Mind in Society* (79-91). Cambridge, MA: Harvard University Press.

Vygotsky begins by looking at various ways to relate learning and development. After discussing short-coming of various approaches, he introduces the concept of the zone of proximal development. He does this by talking about different assessment metrics for development: actual development level comprising those tasks that the learner can complete independently and proximal developmental level comprising those additional tasks that the learner can complete with assistance. The delta defines the zone of proximal development, an area for *optimal* learning; optimal, because those tasks are already in process of being learned.

*Webster’s Ninth New Collegiate Dictionary*. (1991). Springfield MA: Merriam-Webster, Inc.