Learning and teaching domain specific knowledge

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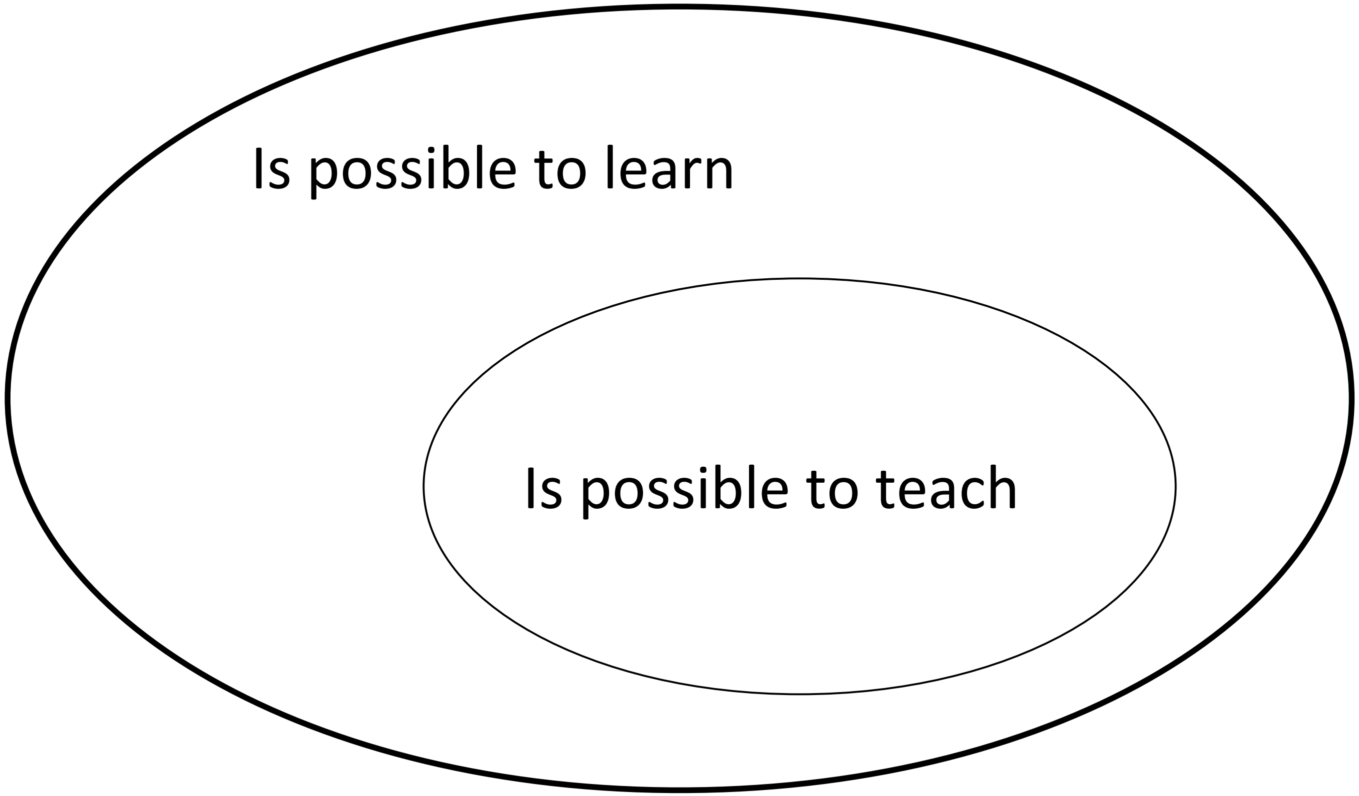
Sensevy's question



An answer to Sensevy

- One possible difference between what is possible to learn / what is possible to teach is
  - Primary knowledge
  - Secondary knowledge

Primary and secondary knowledge
(Geary, 2008)

	Primary knowledge	Secondary knowledge
Utility	Adaptation to *actual* social, biological, and physical environment	Preparation to *future* social and working life
Working memory limitation	No effect	Strong effect
Learning	Unconscious, effortless, rapid. Based on immersion, social relationships, exploration, games.	Conscious, effortful, slow. Based on instruction or on deliberate, long and intense practice.
Motivation	No motivation is needed (or intrinsic motivation)	Extrinsic often needed
Examples	Faces recognition, language speaking	Reading, mathematics

An answer to Sensevy

- Instructional design is a domain where
  - Varying instruction features is the Independent Variable
  - Learning is the Dependent Variable
- The manipulated features
  - Tasks
  - Materials
- Each result is specific to
  - A knowledge
  - A set of conditions
  - Learners
- When a result is replicated by varying knowledge / conditions / learners, then it is considered as valid

Richard Mayer's position

The Overlap Between Theoretical and Practical Research

	No SOI: Addresses a contrived learning situation	SOI: Addresses an authentic learning situation
No SOL: Does not test learning theory		SOI only
SOL: Tests learning theory	SOL only	SOL and SOI

Note. SOI = science of instruction; SOL = science of learning.

Mayer, 2008, American Psychologist

One of the main problems

What is the generality of taught knowledge?

The following arguments come from a paper wrote with John Sweller, currently under review

Aim

- Why educational psychology (and psychology) are often "blind" about domain-specific domain when explaining cognitive performances?
- While
  - Domain specific knowledge is often the best explanation of cognitive performance
  - The evidences are available since the very beginning of scientific psychology
- What are the consequences for educational psychology and instructional design?

Definition

- Domain-specific knowledge is memorised information that is necessary to complete a specified task over indefinite periods of time
- The set of tasks that can't be completed without this knowledge it a "domain"
- Domain-general knowledge can be used to solve any problem in any area
  - Example: Learning to solve problems by thinking of similar problems with known solutions

Problem solving task

- Given two points 200 meters apart from each other. You fix a rope 200.04 meters long between the two points, so it is too long by 4 cm. Now you go to the middle of the two points, 100 meters from each, then, you raise the rope until it is taut.
  - How far is it raised?
- About 2 cm? About 20 cm? About 2 m?
- Now, you should try to solve the problem by using the Pythagoras' Theorem. Feeling better?
- Can I help you?

  $100.02^2 = 10{,}004.0004$

  $100^2 = 10{,}000$

Definition

	People who know Pythagoras' Theorem	People who don't know Pythagoras' Theorem
People who solved the rope problem		No one is here
People who didn't solve the rope problem		

Pythagoras theorem is domain specific knowledge if

The set of problems that can be solved by using Pythagoras' theorem but that cannot be solved if the theorem is unknown is a domain

Back

Back to the definition

- If

  Performing a Task T_x -> Knowledge K_x

- Then we can call

  Kx: specific knowledge

  Domain $D_x = \{T_{x1}, T_{x2}, T_{x3} \dots T_{xn}\}$

  Domain specific knowledge = $\{(T_{x1};K_{x1}), (T_{x2};K_{x2}) \dots (T_{xn};K_{x2})\}$

	K_x	$\neg K_x$
performing T_x	nK_xT_x	$n\neg K_xT_x = 0$
not performing T_x	$nK_x\neg T_x$ *or* $n\neg(T_{xn};K_{xn})$	$n\neg K_x \neg T_x$

The blindness to domain-specific knowledge

1. The history of this blindness in scientific psychology
2. Recognizing knowledge and expertise
3. From expertise research to educational psychology
4. Some evidences about this blindness today
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6. Consequences

Binet (1894) and great mental calculators

- Binet studied the case of Inaudi and Diamanti, two great

Multiplications (CALCUL MENTAL)

	3 × 7	49 × 6	63 × 58	426 × 67	638 × 823	4 279 × 584	7 286 × 5 397	61 824 × 3 976	58 927 × 61 408	729 856 × 297 143
M. Inaudi....	$0^{s},6$		2^{s}		$6^{s},4$		21^{s}		40^{s}	4^{m}
M. Diamandi.		6^{s}	17^{s}	21^{s}	56^{s}	92^{s}	$2^{m},7^{s}$	$3^{m},10^{s}$	$4^{m},35^{s}$	
1er caissier...					4^{s}		13^{s}			
2e caissier...	$0^{s},7$		4^{s}		12^{s}					
3e caissier...	$0^{s},7$		4^{s}							

Binet (1894) and great mental calculators

- Binet's comments:
  - "We see that while Mr. Inaudi usually has a marked superiority, it is less, for the multiplication of small numbers, to a cashier, Mr. Lour. He is the best and fastest "Bon Marche" cashier, who takes only 4 seconds in a case where Mr. Inaudi takes 6.4 seconds to solve the same problem. **These are small operations. Mr. Lour could not continue his superiority for more complex operations, because his memory failed him***.* The discussion of these numerical results raises an interesting question of psychology."
- Before the experiment, Binet interviewed the cashiers: they indicated that a period of about 10 years was required to reach their high levels of mental calculation.

Binet (1982) and Mozart

- Binet reported the anecdote about Mozart and his ability to remember Allegri's Miserere.
  - *When visiting Rome as a fourteen-year-old, Mozart heard the piece during a Sistine Chapel Wednesday service. Later that day, he wrote it down entirely from memory, returning to the Chapel that Friday to make minor corrections.*
- According to Binet, this feat is explained by Mozart's musical memory (Binet also thought that painters like Doré and Vernet have a naturally superior visual memory)
- Our alternative hypothesis
  - Mozart understood that Allegri's piece was tonal music, following the established rules of tonal music. Those rules are known to experienced musicians who know the structure of such music and can reproduce it in a manner very similar to Mozart**. Mozart was a genius but it does not require a genius to remember a music piece belonging to a well-known category**. The transcription of this piece of music is likely to be a routine exercise for highly knowledgeable musicians.

The sad end of the story

- In 1904 Binet was asked to design a standardized test to evaluate if a pupil was likely or unlikely to succeed in secondary school
- Subsequently, this test, used to determine the probability of success in school, was given a new name: “IQ” and pretends to measure “Intelligence”
- If Binet had not been blind when describing his own table, perhaps the story would have been different (intelligence not considered as natural disposition, not considered as gift, where domain-specific knowledge has a important role)

The sad end of the story

- One century after, the “Bell curve” controversy
- Neisser et al. (1996) were mandated by APA to establish an authoritative report on intelligence that all sides could use as a basis for discussion.
- Their conclusion about what is known about the *causes* (or explanations) of intelligence is: NOTHING(!)

Miller (1956) and the musicians

- The paper is one of the main events in the birth of cognitive psychology
- The paper defined the concept of capacity of processing information or short-term memory capacity as universal, applying to everyone in every domain.
- But, when Miller reported results concerning absolute judgment of tones, he wrote:
  - “Most people are surprised that the number is as small as six. Of course, there is evidence that a musically sophisticated person with absolute pitch can identify accurately any one of 50 or 60 different pitches. **Fortunately, I do not have time to discuss these remarkable exceptions. I say it is fortunate because I do not know how to explain their superior performance.** So I shall stick to the more pedestrian fact that most of us can identify about one out of only five or six pitches before we begin to get confused.” (Miller, 1956, p. 84)

Piaget and academic knowledge

- Children at formal operational thought stage (12-13 years old) do not necessarily succeed in performing tasks that imply formal logic knowledge or scientific reasoning
- The same with adults!
- Piaget has (almost) never been focused in academic knowledge acquisition (but many people use Piaget to talk about that!)

Solution to these problems

- Domain specific knowledge can explain
  - performances in mental calculation as well as music transcription (Binet)
  - performances in judgment of tones (Miller)
  - performance in logic, scientific reasoning (Piaget)

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Air traffic controller memory

- Air traffic controller (ATC) memory has been widely studied
- Yntema (1963; Yntema & Mueser, 1960, 1962) tested whether ATC had an enhanced general ability to chunk information. He tested ATC on laboratory tasks such as letters associated with shapes, colours, signs, etc.
  - Results: ATC are no better than the general population
- Bisseret (1970) used the same kinds of tasks but using meaningful materials: description of several aircraft with each description using seven variables.
  - Results: ATC recall 22.8 information (novices) or and 30 information (experts)
- We discussed the results with Bisseret 41 years later
  - He indicated that he would have been better positioned to interpret his results if Ericsson and Kintsch's (1995) concept of long-term working memory been available to him at the time of publication!

Why chess masters win

- De Groot (1946-1965): the only distinction between masters and lower ranked players is in memory for board configurations taken from real games.
  - Masters: 70 – 80% accuracy rate
  - Lower ranked: 30 – 40% accuracy rate
- Chase and Simon (1973) replicated these results and demonstrated that if random board configurations were used,
  - No difference between masters and lower ranked (all having a low success rate)
- Masters are superior to lower ranked players because they had acquired an enormous domain-specific knowledge base

Generalization to other areas

- Findings indicating that experts have a better memory for problem solving states than novices have been obtained in:
  - understanding and remembering text (Chiesi, Spilich, & Voss, 1979)
  - electronic engineering (Egan & Schwartz, 1979)
  - programming (Jeffries, Turner, Polson, & Atwood, 1981)
  - algebra (Sweller & Cooper, 1985)

Expertise Theory

- Chase and Ericsson (1982): The techniques used by exceptional performers to memorise lists of random digits or random letters are readily learnable. People who perform at a high level in memory tests are simply experts in memory test tasks because they have domain-specific knowledge concerning these tasks.
- Expertise in any substantial domain requires years of practice with the intention of improving performance (Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Romer, 1993). It is likely to take a minimum of 10 years to reach the highest levels of performance. During those 10 years, experts are acquiring domain-specific knowledge held in long-term memory.
- The capacity and duration limits of working memory disappear when working memory deals with familiar information from long-term memory.
- The major factor determining the performance of experts is acquired, domain-specific knowledge. The more complex is the domain, the more important is domain-specific knowledge.

Conclusion on expertise

- Ericsson and Charness (1994)
  - it probably took such a long time to discover this simple explanation because we are fascinated by exceptional performance and genius. This fascination may have led us to seek extraordinary explanations.
- But, when considering non-exceptional people, it has taken even longer to recognize the role of domain-specific knowledge.

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Categorisation and the representation of physics problems by experts and novices

- Chi, Feltovich and Glaser (1981) examined the differences between experts and novices in problem representation
- They presented novices and experts with a task in which they were presented with a variety of physics problems that they had to sort into categories.
  - Experts (PhD students in physics) sorted the problems based on structural cues relevant to problem solution
  - Novices (physics undergraduates) used superficial, physical cues.

"The basic expert-novice result, that experts' knowledge is represented at a "deep" level (however one characterizes "deep"), while novices' knowledge is represented at a more concrete level, has been replicated in many domains, ranging from knowledge possessed by scientists to taxi drivers" (Chi, 1993, p. 12).

Categorization and the representation of physics problems by experts and novices

- The Chi et al. article emphasized the differences between experts and novices in educationally relevant problems. It was a major step in recognizing the importance of domain-specific knowledge in education
- Only three years before, the famous Anzaï and Simon (1979) paper concerned problem solving using the Tower of Hanoï puzzle. There is no mention of knowledge!
- Following Chi's work, several studies took domain-specific knowledge into account by controlling it, but only a few focused on analysing the effects of domain-specific knowledge on learning (Fayol, 1994; Amadieu, Tricot & Mariné, 2009; Duncan, 2007; Gijlers & de Jong, 2005; Schneider, Korkel & Weinert,1989; Mayer, Mathias & Wetzel, 2007; Pollock, Chandler & Sweller, 2002).

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Evidences for the neglect of DSK

- Web of Knowledge
  - “cognitive performance”: 5000 articles
  - “cognitive” AND “performance”: 52,000 articles
- Main topics associated with cognitive performance
  1. Memory
  2. Age
  3. Impairment
  4. Deficit
  5. Attention
  6. Learning

  (…) Working memory, Schizophrenia, Depression, Intelligence

  14. Knowledge

  (…)

  20. Instruction

Evidences for the neglect of DSK

- Meta-analyses about cognitive performance (more than 300)
  - schizophrenia
  - personnel selection methods, career and academic interest
  - problem-based learning
  - medial frontal cortex
  - feed-back interventions
  - motivation
  - sleep deprivation
  - age
  - (…)

  Specific knowledge is sometimes mentioned but secondary
- Only one focuses on the effect of prior knowledge on performance and learning (Dochy, Seghers & Buehl, 1999)
  - Strong effect of prior knowledge on performance
  - This paper is far less cited than other meta-analysis

Problem with meta-analysis

- Meta-analyses cannot incorporate in their data experiments and results that have not been carried out.
  - Imagine the following experiment: two groups of students are asked to solve geometry problems requiring Pythagoras' theorem
    - The first group is taught the theorem for one hour before they perform the task.
    - The second group is not taught the theorem but instead is presented instruction about the French Revolution before performing the task.
  - Obviously, this type of experiment is unlikely to be published or even carried out.

Effect of prior knowledge

- Many experiments controlling participants' prior specific knowledge, in academic tasks:
  - text comprehension (Osuru, Dempsey & McNamara, 2009; Tarchi, 2010)
    - particularly with low coherence texts (Kintsch, 1994; McNamara & Kintsch, 1994)
    - hypertext comprehension (Le Bigot & Rouet, 2007; Potelle & Rouet, 2003)
  - animation and multimedia learning (Seufert, 2003; Wetzels, Kester & van Merrienboer, 2011)
  - procedure and skills acquisition (McNamara, 1995)
  - learning facts (Woloshyn, Pressley & Schneider, 1992)
  - performance on exams (Conway et al., 1997)
- The effects of knowledge have been demonstrated in early infancy, with 6-month-old infants (Barr, Rovee-Collier & Learmonth, 2011).
- Prior knowledge effect is so important that it is likely to be impossible to study learning and performance without accurately taking into account domain-specific prior knowledge, including its quality (e.g. accuracy), depth and breadth (Shapiro, 2004)

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- Domain-specific knowledge
  - is by far the best explanation of performance in any cognitive area
  - can be readily taught and learned
- Why were we blind? Maybe because:
  - We are unaware of the huge amount of domain specific knowledge held in our own LTM.
  - The nature of that knowledge tends to be hidden from us as well, e.g. Pythagoras' theorem + recognising the various problem states to which the theorem applies
  - When we know something, we forget how complex and difficult it was to learn.

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Instructional design and Cognitive Load Theory

- Is about domain-specific knowledge acquisition and is probably the first instructional theory about it
- Maybe our definition of domain-specific knowledge could be use in some experiments, to evaluate the specificity – generality of the acquired knowledge?

Thanks for your attention!

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