Artificial Intelligence for Improving Children's Thinking

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Extended Abstract

1 Human Intelligence

There is no universally accepted definition for intelligence among educators and psychologists. One (early) viewpoint regards intelligence as a unitary trait which can be measured by a single IQ test score (such as Binet & Simon, 1905; Terman, 1925). This view has now largely been replaced by the multiple-intelligence conceptions (such as Guilford, 1967; Renzulli, 1986; Gardner, 1983). We have chosen the definition of multiple intelligences by Gardner (1983) for our discussion here, since it is widely accepted among educators and psychologists.

Gardner (1983, 1993) divided intelligence into seven aspects. He claimed that these multiple intelligences are separate and somewhat independent, based partly on evidence from patients who suffer certain brain damages which often disrupt one aspect of intelligence but not the others. Briefly, the seven intelligences are

1. Linguistic intelligence
2. Logical-mathematical intelligence
3. Spatial intelligence
4. Musical intelligence
5. Bodily-kinaesthetic intelligence
6. Interpersonal intelligence
7. Intrapersonal intelligence

Note that the first two intelligences, linguistic and logical-mathematical intelligences, are included in competencies measured by traditional intelligence tests.

2 Artificial Intelligence and Cognitive Science

Cognitive science studies how the human mind works (mental processes), drawing from various disciplines such as psychology, Artificial Intelligence (AI), linguistics, and neuroscience. AI regards the human brain as an information-processing device.[1] As correctly pointed by Allen (1998), most previous definitions of AI use the word *intelligence* in its definition[2], leaving the term completely unexplained. Allen (1998) gives a one-sentence definition of AI as "AI is the science of making machines do tasks that humans can do or try to do".

Two additional clarifications may be added to his definition. First, we do not require a single machine or AI system to do all the tasks that humans can do. Significant progress has been made in various areas of artificial intelligence (see later) in the last 40 years. Second, AI strives to outperform or surpass in doing tasks that humans can do, by certain performance measurements. Therefore, we want to build not just a chess-playing computer, but one that wins the game against the best human players.

Progresses made in various areas of AI can be linked with the multiple intelligence theory of Gardner (1983):

1. Linguistic intelligence – computational linguistics, spoken language recognition and synthesis, etc.
2. Logical-mathematical intelligence – logical reasoning, problem solving, etc.
3. Spatial intelligence – computer vision, spatial and imagery reasoning
4. Musical intelligence – AI and music understanding and creation
5. Bodily-kinaesthetic intelligence – robotics
6. Interpersonal intelligence – AI agents that interact to each other
7. Intrapersonal intelligence – self-awareness and emotion in AI

In various areas of AI, researchers have succeeded in constructing AI systems that match or surpass human performance (for example, Ling & Marinov, 1993, 1994). Many general and powerful principles, methodologies, and algorithms, originating in human introspection and intuition, have been developed. They are able to solve a variety of problems in a certain domain.

This gave us a new idea: many of these AI principles and methods can be taught back to humans to

[1] The computational power of a brain is estimated to be a billion times faster than the most powerful computers today, due to the massive parallelism of the brain (Russell & Norvig, 1997).

[2] For example, a common definition of AI is to make computers to do the work that requires human intelligence.

improve our thinking abilities and skills. This would be especially beneficial to children, since childhood is the critical period to learn thinking skills. Learning high-level thinking skills is also the central task of the current education.

3 AI in Education

AI has appeared in education for about twenty years, mainly in the format of intelligent tutoring systems (see, for example, Proceedings of International Conference on Intelligent Tutoring Systems; Proceedings of International Conference on AI and Education; and Sleeman & Brown, 1982; Wenger, 1987). Briefly, AI tutoring systems comprise educational software that teaches certain subjects (such as algebra) to users. Such systems use AI to access individual users' weaknesses and knowledge, building up user profiles or models and adjusting materials and teaching styles along the way.

As far as we know, very little has been done in teaching AI principles and methods as the *content* in AI tutoring systems, or any education systems. The work presented here seems to be quite unique.

4 Teaching AI Methods to Children

Linguistic and logical-mathematical intelligences, the first two intelligences in Gardner's definition, are crucial aspects of high-level thinking and intellectual processes. However, there are many other thinking abilities that are not explicitly represented. Therefore, we combine the first two intelligences, and give them a new name: *intellectual intelligence*, and add more components into it. Below is our definition of multiple intelligences.

1. Intellectual intelligence
   - Thinking strategies (including Gardner's logical-mathematical intelligence; see later)
   - Language (Gardner's Linguistic intelligence)
   - Knowledge
2. Spatial intelligence
3. Musical intelligence
4. Bodily-kinaesthetic intelligence
5. Interpersonal intelligence
6. Intrapersonal intelligence

The category of thinking strategies can be further divided into several subareas:

- Processing abilities
  - Logical reasoning
  - Rational reasoning and optimal decision making
  - Critical thinking
  - Inductive learning and generalization
  - Analogy
  - Problem solving by search
  - Planning
  - Problem-solving strategies
  - ...
- Generative abilities
  - Creativity and divergent thinking
  - Imagination
  - ...

We believe that it is important to separate high-level thinking strategies from knowledge and language since they underlie other mental activities and operate upon domain knowledge. Such a detailed breakdown of thinking strategies can also help us to focus on specific and different thinking abilities, which directly correspond to various areas of AI. We can then teach, systematically, AI principles and methodologies in areas of AI to children to improve their thinking and problem-solving abilities.

Table 1 lists some of these thinking strategies and their corresponding AI principles and methodologies. A few examples of thinking puzzles, games, and educational software through which these thinking methodologies are taught are also included in the table.

As an example, lateral thinking puzzles are excellent for developing critical thinking skills and creativity. The instructor poses a puzzle (for example, *a man is dead in a field with a unopened package next to him. Why did he die?*), and students can ask only yes/no questions. The instructor answers these questions faithfully with yes, no, or irrelevant, according to the correct answer. The goal of students is to find out the instructor's solution by asking as few questions as possible. This fascinating game also resembles the scientific discovery and investigation process in which scientists design critical experiments to find out answers to some anomalies.

The AI principle for critical thinking is hypothesis-space reduction (as version-space reduction in machine learning): Every question should eliminate half of the hypothesis-space, no matter if the answer is yes or no. Children are then taught that it is not just half the number of the hypotheses, but half of the possibilities (some hypotheses may be much more likely than others). This teaches children about probability estimation and updating of likely events.

As we can see, these AI principles and methods are quite general since they are knowledge-independent, capable of solving various problems of the same kind.

Table 1: Different aspects of intellectual intelligence, their corresponding AI principles and methodologies, and games used for instruction.

Intellectual Intelligence	**AI Principles and Methodologies**	**Thinking Games**
Critical thinking (Ask key questions)	Hypothesis-space reduction Belief revision	20-question puzzles Lateral thinking puzzles Scientific investigation
Logical reasoning (Deduction)	Inference rules (Modus Ponens, etc.) Proof by negation	Minesweep, Mastermind Three-muddy-boy puzzle
Rational reasoning and optimal decision making	Probability estimation Utility theory	Betting, lottery Decision making in daily life
Inductive learning and analogy	Occam's Razor Complexity of concepts	Logic Journey of the Zoombinis 1, 2, 4; what comes next?
Problem solving by search and planning	Search strategies, heuristics Constrain satisfaction heuristics	Sokowin, 8 puzzles Maze, Cryptarithmetic
Problem-solving strategies	Divide-and-conquer Recursion	Motor programming in Dr. Brain Hanoi Tower

They also resemble meta-cognition (how to think) that educators often talk about and strive to teach to children. Acquiring such high-order thinking strategies that can be applied to other new problems in school and in life *is* the ultimate goal of learning.

In recent years, this educational and pedagogic paradigm of stressing the importance of learning how to learn instead of merely learning domain facts and rules of application has gained considerable supports in schools, and AI's role in education is also being expanded (Andriessen & Sandberg, 1999). We believe that teaching AI for improving children's high-level thinking abilities is a fascinating new application of AI in education.

The AI principles and methodologies are also quite concrete, since they could be illustrated in detailed steps, just as computer algorithms, through thinking games and puzzles. Notice, though, that in most cases the correspondence is not at the algorithm level: it would be impossible to teach children (or adults) the exact A^* search algorithm, or any mechanical theorem-proving process. However, the principles can certainly be acquired and carried over to new tasks. For example, after learning principles of problem solving by search, a 9-year-old girl showed me that the 4-missionaries-and-cannibals problem[3] has no solution by exhaustively examining the whole state-space (while avoiding repetitive states), even though the order of states searched is not as well organized as in the A^* algorithm.

I have been running a "Creative Kids Workshop" on weekends over the last two years for elementary-school children, and found that this fashion of top-down teaching of thinking skills very effective. Instead of just doing thinking puzzles (some schools do not even do that often) and hoping that children would develop high-level thinking skills themselves someday, children are *directly* taught thinking methods, which are illustrated repeatedly through different examples, puzzles, and games. It is my belief that this top-down teaching of thinking skills is much more effective than the bottom-up (problem-driven) approach.

It is also possible, although very difficult at present, to design AI tutoring systems that teach AI thinking methods. One main difficulty is the open-ended and interactive nature of the teaching environment (as the one in the Creative Kids Workshop). For example, when doing lateral thinking puzzles during the Workshop, unexpected questions are often asked, and clarification and disambiguation needed. This requires a large amount of common-sense knowledge. In addition, whether a question is good or not depends on the sequence of the questions. It is still very difficult to design an AI system that can answer such open-ended questions in unconstrained natural language.

5 Future Research and Challenges

Table 1 should certainly be expanded to include more thinking strategies that can be taught with AI principles and methods. Although much positive feedback has been obtained from children and parents attending Creative Kids Workshops, large-scale studies and formal evaluations must be implemented to access effectiveness.

The AI methods described are taught in isolation. Given a problem, there is no "super" AI system that can decide what kind of problem it is, how to formulate it, and which AI methods to apply. Acquiring this integrating strategy would be crucial for choosing and applying various thinking strategies in real-world new situations. But little is known as to how to do that in AI, or how to teach it to our children.

Creativity also represents a crucial aspect of intellectual intelligence. Much work is needed to bring methodologies in AI to improving creativity in children.

Several parents sat in on the whole Creative Kids

[3] The classical 3-missionaries-and-cannibals problem can be found in (Russell & Norvig, 1997, page 67).

Workshop themselves and were very positive about their own learning experiences. Indeed, reasoning, critical thinking, creativity, and optimal decision making under uncertainty are situations that business people often have to deal with, just as we have to in our daily life. Application of AI methods to improve adult thinking abilities is also a future area to look into.

Last, as we discussed earlier, designing AI tutoring systems for teaching high-level thinking skills is also a major challenge in the future research.

Acknowledgements

The author thanks Gord McCalla for useful discussions, and Jerry Andriessen for providing me with his paper to be published in IJAIED. This research is partly supported by an NSERC Research Grant.

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