Winona State Physics

reasoning_ability:start

Reasoning Ability and Cognitive Acceleration

What is Reasoning Ability?

The two pictures at right are drawn by chldren (a 1st grader and a 3rd grader) in response to the task, “Draw a house on the side of a mountain. There are trees on the mountain. The house has a chimney, and there's smoke coming out of the chimney. It is calm day.”

While people may disagree about what specifically constitues reasoning ability[1], it should be obvious that in the two pictures at right, different representations of reality are being presented. The two children are making models of the situation in their minds (or perhaps on paper), and their models have varying degrees of predictive power.

On a hand-waving level, the creation of predictive models of reality seems like a useful working outcome of a well-developed reasoner. Along these lines, see the lovely student work in “Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners,” Schwarz et. al., J. Res. Sci. Teach, 46, 6, (2009).

Michael Shayer and Phillip Adey published a useful taxonomy of reasoning ability in their excellent book, “Towards a Science of Science Teaching,” which is now out of print, but available used[2]. In the taxonomy, they suggest 15 different skills that are useful in approaching scientific and mathematical problems. For each skill, expected student performance is divided up along Piagetian categories, using a specific scale that maps to the Concrete/Transitional/Formal reasoning progression.

The list, ”Curriculum Analysis Taxonomy” is included in the training materials for the Thinking Science (CASE) materials. Philip Adey passed away on January 31, 2013, but gave me permission to distribute the taxonomy freely, “spread the CAT as widely as you like!” he said in an email.

Can you measure Reasoning Ability?

Yes.

Shayer and Adey developed several Piagetian “Science Reasoning Tasks”[3] which map to a useful and considerably detailed scale. In a parallel vein, Anton Lawson has developed and written about a “Classroom Test of Scientific Reasoning” (CTSR), which is fairly well-known in US educational circles.

Further, John Deming, Jacki O'Donnell, and Chris Malone completed a 6000+ student survey of CTSR scores. Their work, published in Winter 2012, allows the CTSR to be used (by a teacher) as a meaningful benchmarked norm. In taking the data, they were able to look at the relationship between school average CTSR scores, and school average scores on the Minnesota Comprehensive Assessment (MCA). Some of the data from their work is shown at right. Interestingly, CTSR average seems correlate with MCA performance stronger than than percent free/reduced lunch (poverty).

Figure 1

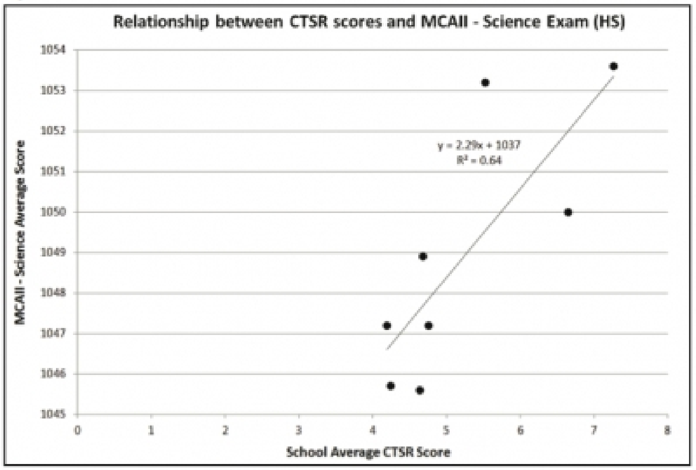


Figure 1: This figure illustrates the link between reasoning ability and relative science achievement. Each point represents one Minnesota school, comparing its average CTSR score to its average MCA II - Science score.

Figure 2

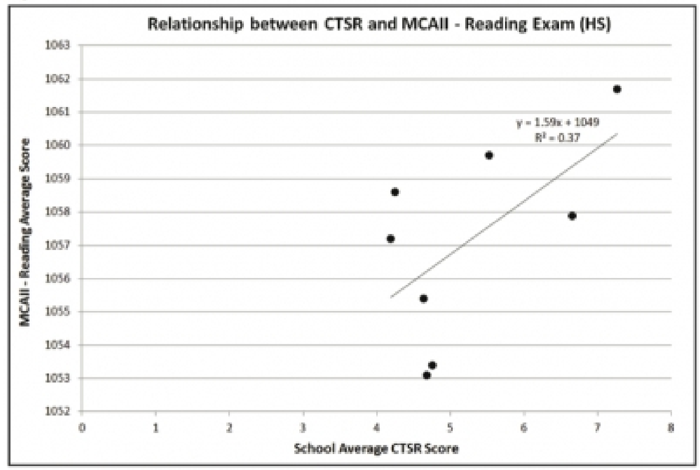


Figure 2: This figure illustrates the link between reasoning ability and relative reading achievement. Each point represents one Minnesota school, comparing its average CTSR score versus its average MCA II - Reading score.

Figure 3

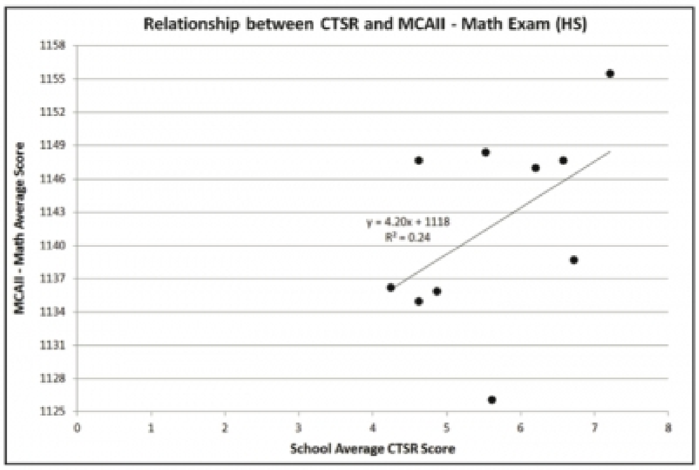


Figure 3: This figure illustrates the link between reasoning ability and relative math achievement. Each point represents one Minnesota school, comparing its average CTSR score to its average MCA II - Math score.

Figure 4

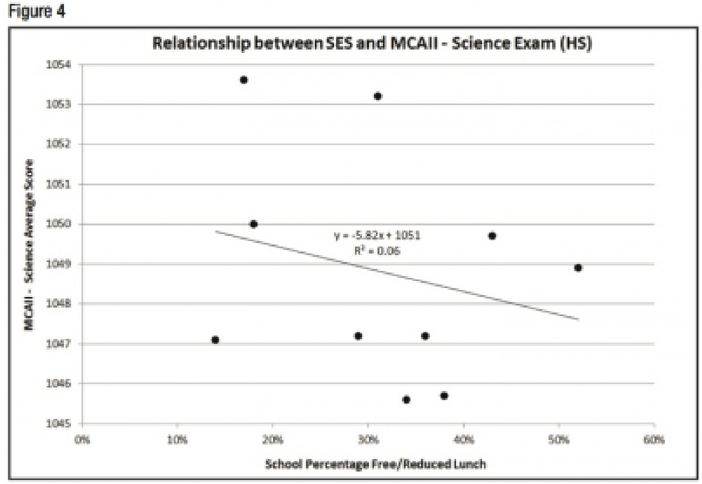


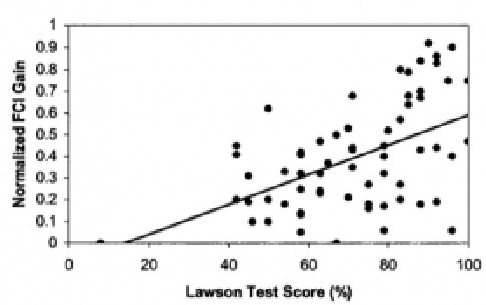
Figure 4: This figure illustrates the link between a school's average socio-economic status (as measured by the school's percent of students who qualify for free/reduced lunch) and that school's average MCA II - Science score. Each point represents one Minnesota school.

References:

1. A.E. Lawson, J. Res. Sci. Teach. 15, 11 (1978)
2. Anton Lawon's homepage [http://www.public.asu.edu/~anton1/]
3. “Scientific Literacy: Resurrecting the Phoenix with Thinking Skills,” Deming, O’Donnell, and Malone, Science Educator, Winter 2012 Vol. 21, no. 2.
4. Frameworks for Inquiry [https://sites.google.com/site/wsuinquiryinstruction/home], which summarizes much of Deming and O'Donnell's work to date.

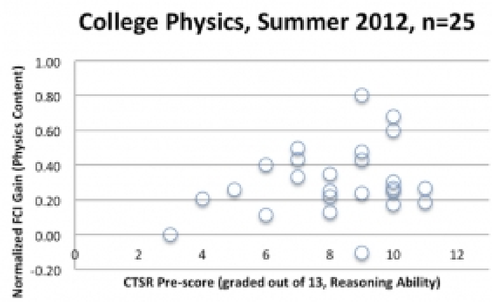
Why is Reasoning Ability Important?

In physics, one paper stands out. In “Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability,” Coletta and Phillips give the CTSR and the Force Concept Inventory (FCI, a conceptual measure of newtonian physics knowledge) to a large number of students. The CTSR is given as a pretest, and the FCI post and pre so that a normalized gain can be computed. The figure at right (from the paper) shows the strong (predictive?) relationship between a student's incoming CTSR score (reasoning level) and their ability to learn physics (attain a high FCI gain).



In effect, the data seems to say that it is very difficult (perhaps impossible?) for a student with a low incoming CTSR score to show substantial gain on the FCI (ie, learn a lot of physics).

This effect is fairly repeatable. The second figure at right is data from one of my own sections of Physics 201 at Winona State University.



Beyond these simple correlations, it is important to be aware that reasoning ability has decayed precipitously since the 1970's. In 2007 and 2009, Shayer, Ginsburg, and Coe published a series of measurements made with the **same test**[4] since the 1970's. In a hand-waving sense, the data show that 7.5 year olds in 1976 and 11 year olds in 2003 reason at roughly the same level.

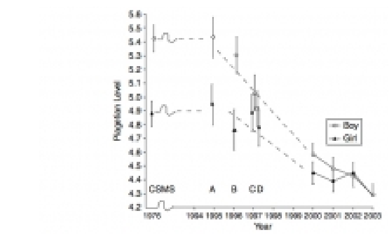


Figure 2. Boys/Girl means on Volume & Heaviness in various data 1976 to 2003.

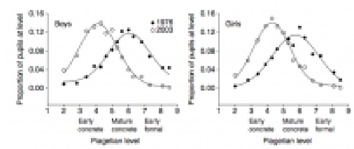


Figure 1. Comparison of performance for boys and girls on Volume & Heaviness 1976 to 2003.

References:

1. “Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability,” Coletta and Phillips, Am. J. Phys. 73, 12, 2005.
2. "Why you should measure your students' reasoning ability," Coletta, Phillips, Steinert, The Physics Teacher, 45, 2007.
    a. "A case study of student performance following a switch to modeling-based Physics first course sequence," Schuchardt, Malone, Diehl, Harless, McGinnis, Parr. Paper presented at the National Association for Research in Science Teaching annual conference, Baltimore, MD.
3. Deming and Cracolice, “Inquiry Instruction in High School Chemistry and its Effect on Students’ Proportional Reasoning Ability,” NSTA 2009.
4. “Thirty years on – a large anti-Flynn effect? The Piagetian test Volume & Heaviness norms 1975–2003,” Shayer, Ginsburg, and Coe, British Journal of Educational Psychology (2007), 77: 25–41.
5. “Thirty years on – a large anti-Flynn effect (II): 13- and 14-year-olds. Piagetian tests of formal operations norms 1976–2006/7,” Shayer and Ginsburg, British Journal of Educational Psychology (2009), 79: 409–418.

Can Reasoning Ability be Changed?

Yes.

Obviously, as a child develops, their ability to make predictive models about the world also develops, though, as mentioned, this development has decayed over the past 30 years.

More importantly though, Shayer and Adey have developed an approach to education, “Cognitive Acceleration,” in which students participate in experiences that stimulate the development of their reasoning ability. An excellent summary of their work is the book chapter, "The Effects of Cognitive Acceleration – and speculation about causes of these effects." Philip Adey and Michael Shayer, King's College London.

When giving a talk, Adey would often talk about the initial “proof of concept” of the approach: In the late 1990's, these lessons were implemented at a number of schools in the UK with pupils aged 11-13. Three years later, these students scored, on average and compared to students who had not received the “treatment” of working on the Cognitive Acceleration lessons, about a letter grade higher on the national GCSE exams (roughly equivalent to the SAT/ACT) than their incoming ability (at age 11) would have predicted. See the figure at right for school averages.

Given the science context used in the interventions, the authors anticipated higher science scores - but the surprising part of the study was that student scores were higher than predicted in science, math, and english subject areas. A plausible explanation for these data is that the Cognitive Acceleration materials stimulate the development of a generalized processing ability, which all academic subjects utilize. The papers describing this measurement compare the schools implementing Cognitive Acceleration with a number of controls, and clearly demonstrate that the growth seen was not a result of normal maturation.

What does CASE look like in practice? See either of the following videos

1. http://archive.teachfind.com/ttv/www.teachers.tv/videos/cognitive-acceleration.html [http://archive.teachfind.com/ttv/www.teachers.tv/videos/cognitive-acceleration.html]
2. Philip Adey speaking at a meeting in 2007 [http://www.thinking.ep.liu.se/thinking2007/thinking_conference2007.asp?

MOVIE=dag02_p_adey]

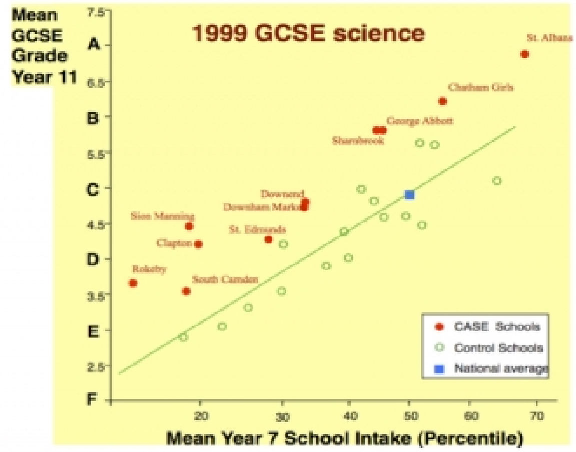


Figure 4a: the effect of CASE intervention on GCSE science grades

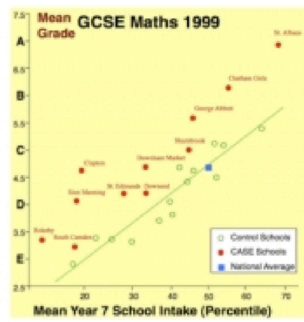


Figure 4b: Effect of CASE on Maths
(Figures from Shayer 1999a)

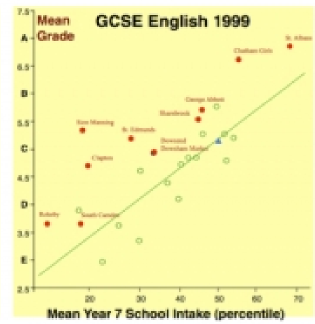


Figure 4c: Effect of CASE on English

Personally speaking, I've found the implementation of CASE in Finland to be more even compelling than these impressive results because it shows a way to *change* a culture. From Shayer and Adey's summary,

> In what must rank as an extremely rare example of a true randomised controlled experiment in education, Jorma Kuusela (Hautamäki, Kuusela, & Wikström, 2002) took the whole population of Year 6 (age 12+) from all of the primary schools in one town, Vihti (population 23,000) in Finland as their sample. The final study sample was 276 students who were randomly assigned regardless of their normal school or class to one of three conditions: CASE, CAME, or no treatment, each condition containing 92 students. The children were transported around the town in buses and taxis to attend the CA lessons all administered by Kuusela himself to groups of about 23. It must have been a logistical nightmare. The intervention program was only for one year rather than the normal (for CASE and CAME) 2 years and consisted of weekly CASE or CAME lessons of 90 minutes duration.
>
> All students were pretested at the start of Year 6 and then given immediate post test at the end of Year 6 and delayed tests at the end of Year 7 and again at the end of Year 8. The test battery, for which Finnish normative data was available, accessed higher cognitive functions (Ross & Ross, 1977) (four scales: deductive reasoning, missing premises, relevant-and-irrelevant information, questioning strategies) and mental arithmetic (WISC-Arithmetic with one extra (last) item from Volume and Heaviness of PRT[5]s). Post tests included two PRTs. Other, qualitative, factors were also assessed.
>
> The surprising results of this experiment were that not only did the CASE and CAME treatment groups make significant advances in cognitive development compared with national norms, but so did the control group! The CASE and CAME groups made slightly larger gains than the controls but the differences did not reach significance. On the other hand, at immediate post-test all of the Vihti students showed a gain of more that one s.d. against national norms, highly significant.
>
> On the average, about 15 % of 13-year-olds and about 19 % of 14-year-olds are formal thinkers in Finland, and the pre-tests had established that the Vihti school population was near to average.
>
> In hindsight it is not so difficult to explain this initially surprising result in terms of social construction. Consider what it must have been like in each Year 6 class in Vihti that year. Each week first one third of your class is taken away to a CAME lesson, then another third are taken away to a CASE lesson. Do the students not talk with one another when they are reunited? Do the CASE and CAME students, two-thirds of the class, not question more, probe more deeply, generate more constructive arguments?
>
> In the words of the authors: “Children do not learn only from teachers, but they learn in the most profound way also from each other.” (Bateson, 1979) interprets this as the context of the lesson (for the teacher) having been changed by the change in learning strategies of their students so the teacher had (without realising it?) also changed from that feedback

Finally, I should mention that I have made use of Cognitive Acceleration materials in my work at Winona State University. A summary of results thus far is given in, "Using Cognitive Acceleration Materials to Develop Pre-service Teachers’ Reasoning and Pedagogical Expertise," Moore, O'Donnell, Poirier. Conference Proceeding, 2012 ASQ Advancing the STEM Agenda in Education, the Workplace and Society. University of Wisconsin-Stout July 16-17, 2012

References

If you'd like help finding copies of these or other articles cited, please feel welcome to contact me, Dr. Nathan Moore [mailto:nmoore@winona.edu], Department of Physics, Winona State University, USA.

- “Towards a Science of Science Teaching,” which is now out of print, but available used((Heinemann Educational Books,

1981. (ISBN-10: 0435-57825-1, ISBN-13: 9780435578251)

- Shayer and Adey's Curriculum Analysis Taxonomy, from Thinking Science, materials of the Cognitive Acceleration through Science Education (CASE) Project.
- “Scientific Literacy: Resurrecting the Phoenix with Thinking Skills,” Deming, O’Donnell, and Malone, Science Educator, Winter 2012 Vol. 21, no. 2.
- “Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability,” Coletta and Phillips, Am. J. Phys. 73, 12, 2005.
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- "The Effects of Cognitive Acceleration – and speculation about causes of these effects." Philip Adey and Michael Shayer, King's College London.

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1) indeed, I was once told that “there's no such thing as `Formal` reasoning ability,” by a very accomplished Physics/Education PhD

2) Heinemann Educational Books, 1981. (ISBN-10: 0435-57825-1, ISBN-13: 9780435578251) contact me [mailto:nmoore@winona.edu] if you need help finding a copy

3) which are controlled, contact me [mailto:nmoore@winona.edu] if you need help finding a copy

4) specifically in the case of the first article

5) Piagetian Reasoning Tasks, see “Towards a Science of Science Teaching.”

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