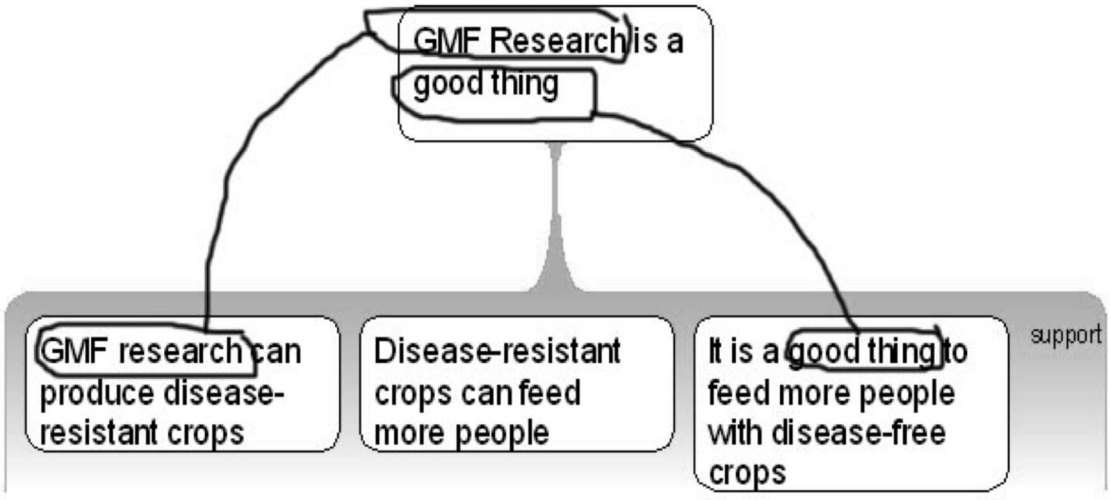
Erratum

On page 24 of the previous issue of ***INQUIRY*** (Vol. 27, No. 2), the issue in which Part I of Martin Davies's article on argument mapping appeared, a diagram that was to accompany the discussion of the "Rabbit Rule" was unfortunately omitted in the production process. We apologize to the author for the error, and here is what the diagram and the accompanying text should have been:

The Rabbit Rule: The Rabbit Rule, also suggested by Neil Thomason, is a special case of the Holding Hands rule, except it is applied *vertically* in an argument map, i.e., between premises and the contention, rather than horizontally between the premises. This is an even more important rule as, in all valid arguments, the contention needs to be supported by suitable inferences from terms provided in the premises. Teachers of argument mapping find that students easily remember this rule if they remind them "No rabbits can pulled out of hats" (i.e., by magic) when argument mapping. One cannot conclude something about "X", unless "X" is given in one or other of the premises (Rider & Thomason, 2008). The Rabbit Rule is illustrated below.



Computer-Aided Argument Mapping and the Teaching of Critical Thinking: Part II

Martin Davies
University of Melbourne

Abstract

Part I of this paper outlined the three standard approaches to the teaching of critical thinking: the normative (or philosophical), cognitive psychology, and educational taxonomy approaches. The paper contrasted these with the visualisation approach; in particular, computer-aided argument mapping (CAAM), and presented a detailed account of the CAAM methodology and a theoretical justification for its use. This part develops further support for CAAM. A case is made that CAAM improves critical thinking because it minimises the cognitive burden of prose and the demands that arguments in prose typically place on memory. CAAM also has greater usability, complements the imperfect human cognitive system, and adopts a logic of semi-formality which is both natural and intuitive. The paper claims that CAAM is an important advance given that traditional stand-alone critical thinking courses do not teach critical thinking as well as they as they are assumed to do. It is also important given that tertiary education fails to deliver improvements in critical thinking gains for too many students. The paper outlines results from a number of empirical studies that demonstrate that CAAM yields robust gains in critical thinking as measured by independent tests. Students themselves also believe CAAM to be beneficial as noted in coded responses to surveys. I conclude the paper by comparing the traditional approaches to the teaching of critical thinking to the visualisation approach. I argue that CAAM should taken seriously in the context of contemporary educational practices.

Key words: Key words: Critical thinking, argument analysis, computer-aided argument mapping, argument mapping, Rationale.

1. Introduction

Part I of this paper (Davies 2012) concluded with a summary of the theoretical justifications why CAAM might be a useful way to teach critical thinking skills. I begin this part by outlining practical justifications as well. This consists of three main points: usability, complementation, and semi-formality. After this, I summarise the empirical evidence supporting the CAAM approach. I conclude by summarizing the differences between the visualisation approach and more traditional approaches to the teaching of critical thinking.

2. Practical Justification for CAAM

2.1 Usability

A practical reason why argument maps appear to work better compared to the prose alternative, when it comes to teaching the argument analysis component of critical thinking, concerns the greater usability of maps. Usability is a comparative, not an absolute term in this context. It is not being suggested that argument maps are more usable on some kind of independent, objective metric. Rather, I am claiming—as does van Gelder (2007)—that argument mapping is often simply better than prose alternative. Mapping, I believe, constitutes an advance on ways of representing reasoning in the same way as the typewriter constituted an advance in representing thought compared to handwriting using a fountain pen. Similarly, the word processor constituted an advanced over the typewriter for meeting the same objective (van Gelder, 2007).

Historically, humans have always used specially designed tools to help them achieve various aims. The fountain pen, ballpoint pen, typewriter and word processor represented a series of technical improvements in the use of tools in ways of making thoughts visible, and thereby able to be communicated. When it comes to representing reasoning, however, the lineage in the use of tools for this purpose is less clear. Aside from the use of visual forms of representation of arguments by a very small percentage of the population (Toulmin diagrams, Venn diagrams), humans still overwhelmingly read and process arguments only in prose. Why is this? It is hard to think that the reason is any more than historical precedent. It might also be because to date there has been no suitable tool which humans have found which has been suitable for the task. However, with argument mapping there may now be a tool.

I claim that there is no compelling reason to continue using prose as the *only* means of transmitting and processing arguments if there are better ways to do

so. My point is not, of course, to replace prose, but to *augment* prose with software specially designed for the purpose of creating maps of arguments. Argument maps provide this ability. Using "argument processors" like *Rationale*™ is the way of the future when it comes to teaching critical thinking. Empirical evidence for this is provided in Section 4 of this paper.

2.2 Complementation

This is another pragmatic reason to think of argument mapping as an advance on prose representations of arguments. This point follows from the previous point about usability and the remarks made earlier about the cognitive burden of prose, cognitive complexity and the limitations of human memory (See Davies, 2012, Part I, Section 6). Visual representations and displays, such as maps, naturally complement our very imperfect cognitive apparatus. The human brain is a product of evolution and constitutes a system that is very well adapted to meeting survival needs. This includes living in a group of social animals, communicating with each other, finding shelter, food, mating, and rearing our young, amongst others. To a certain degree, making basic inferences is one of those survival skills. However, the ability to process long, complex arguments expressed in dense prose is clearly not one of those survival skills. This is a very recent requirement of the sophisticated animal that the human being has become, and it has occurred relatively recently in our evolutionary development (van Gelder, 2007). It is to be expected that the brain has not evolved this skill, as it is not central to human survival. Like the ability to process complex mathematical equations, cultural evolution has, to a degree, outstripped survival needs, and we require the assistance of technology to aid us in these areas. For complex mathematical equations, we use a calculator or a computer. However, for processing complex arguments, we have yet to make the leap from the traditional method of processing prose to the use of dedicated software for representing arguments. However, this technology now exists. It constitutes, I think, a natural *complement* for us in doing what our imperfect brains cannot do well unaided: namely, critical thinking.

2.3 Semi-formality

A final pragmatic reason for considering argument mapping a new tool for representing arguments concerns its semi-formality. In argument mapping, there is no expectation that users are required to master and use the abstruse symbolism of formal logical systems. Rather, the argument mapping technique more closely approximates the "ordinary language" critical thinking that we normally use in daily life. It puts into visual form what seems natural to us: if an unusual or non-trivial claim is made, and we are in a clear frame of mind, we require a reason, or reasons, to believe it, and then evidence to support the reason(s). Without this, we generally find assertions unacceptable. Argument mapping is based on this semi-formal reasoning.

In van Gelder's words: "there is a 'sweet spot' somewhere on the spectrum between ordinary informal practices at one end, with their sloppiness and disorder, and purely formal techniques at the other, with their rigidity and limited range of application" (van Gelder, 2007, p. 17). Argument mapping provides this "sweet spot." Beyond being required to clearly express propositions in the form of grammatically complete, singular declarative sentences, eliminating any unnecessary words that do not bear directly on the argument being made, and providing evidential links for any claims that are specified, there are no further demands on the user. Formal logic is not required. This means that argument mapping, potentially at least, provides a very natural means by which students can learn to be better critical thinkers. I provide evidence that it does in this paper.

3. Traditional Courses in Critical Thinking Don't Work As Well As They Might

I make the case for argument mapping as a valuable new way of teaching critical thinking in three steps: first, I provide evidence that traditional courses in Philosophy have little impact, second, those Philosophy courses that are specifically designed to teach critical thinking do work, but not as well as they might; third, I provide evidence that courses in critical thinking taught using the argument mapping method do appear to produce greater results than courses without argument mapping. This triple-pronged approach provides prima facie support for idea that the argument mapping approach to teaching critical thinking is long overdue.

3.1 Does Teaching Philosophy Improve Critical Thinking Skills?

Others have in fact, already done the first step in my argument. Here I merely summarise their results. In a strikingly original master's thesis completed at the University of Melbourne, Claudia María Álvarez Ortiz (2007) has investigated the widely held assumption that philosophy courses improve skills in critical thinking, and found the evidence wanting. Long assumed to be the case, Álvarez Ortiz puts to the test the claim that courses in Philosophy (and training in Logic in particular), actually improve critical thinking skills.

Álvarez Ortiz notes the pointlessness of basing any assessment about purported gains in critical thinking just on a literature review of the very divergent empirical studies in this area. This is because the literature uses very different sampling techniques, different standard measures of critical thinking, and compares different outcomes (her review mentions the empirical literature in the area known as Philosophy for Children, as well as studies from both undergraduate and graduate courses in critical thinking) (Alvarez, 2007, pp. 35-50). She

also draws attention to the misleading nature of a "vote counting" approach, where the number of studies which show a positive gain are simply weighed against those that do not, as studies might have very different population sizes (pp. 53-54). She concludes that a meta-analysis of the results of the empirical literature that compares the effect sizes of the extant studies, and which enables comparison in both the magnitude and direction of the purported gains, is the only sensible way to proceed.

However, the results obtained from this method are not encouraging for those that assume that the study of Philosophy improves skills in critical thinking. She bases her meta-analysis on three research questions:

1) To what extent do critical thinking skills increase for students studying Anglo-American analytic philosophy?;
2) To what extent do critical thinking skills increase for students studying subjects other than Anglo-American analytic philosophy?; and
3) To what extent do critical thinking skills increase for students studying critical thinking (CT) in a course specifically designed to teach those skills either as a philosophy course or outside philosophy?

She also uses two independent variables: the amount of philosophy instruction received, and the amount of critical thinking instruction received. Moreover, she includes in her study only empirical studies that are of no less than one semester of instruction in duration. By way of investigating her research questions, she also appears to find data supporting computer-aided argument mapping as a technique; in particular an approach known as "LAMP" (see below).

Álvarez Ortiz classifies the various studies into the following seven groups (I include the labels for each group provided by Álvarez Ortiz, p. 60):

1. *Pure Phil:* CT taught by means of explicit instruction via standard philosophy courses (Ethics, Introduction to Philosophy, etc.); subjects intended to "promote a critical attitude" (Alvarez Ortiz, 2007, p. 58);

2. *Phil CT, No AM:* CT taught in philosophy departments, and which explicitly teach critical thinking using traditional didactic techniques such as questioning and conventional lectures, but which do not teach the use of argument mapping (AM);

3. *Phil CT AM:* CT taught in philosophy departments using traditional didactic techniques, and including some use of argument mapping;

4. *Phil LAMP:* CT taught in philosophy departments using unconventional techniques (in particular, AM), and including a considerable amount of practice with mapping in classes (hereafter: Lots of Argument Mapping Practice, or LAMP);

5. *No Phil, Ded-CT:* Courses taught in other departments (not philosophy), but which offer programs designed and dedicated to teaching critical thinking;

6. *No Phil Some CT:* Courses taught in other departments (not philosophy), and which do not explicitly teach critical thinking, but which offers some pedagogical strategies in class for improving these skills (e.g., critical writing);

7. *No Phil, No CT:* Courses in subjects other than philosophy with no attempts in teaching CT.

What does the data demonstrate? Based on a statistically significant sample size of fifty-two separate studies, which reported one hundred and nineteen research findings, and using a single semester's gains in CT as the measure, she finds the following (the numbers in parentheses refer to the separate groups noted above):

1. Comparing groups (1-3) and (5-7) above. There are significant CT gains for subjects taught in Philosophy (with or without explicit teaching of CT), compared to subjects taught outside Philosophy (with or without explicit teaching of CT) ($p<.01$). This seems to indicate the studying Philosophy improves critical thinking compared to studying non-Philosophy subjects. But the gains are, surprisingly, not great.
2. Comparing (1) and (7): Pure Philosophy courses with no specialised CT component, do not unambiguously demonstrate appreciable gains in CT over a semester than other non-Philosophy courses with no explicit training in CT. The confidence intervals overlap only slightly. ($p<.05$);

Álvarez Ortiz then compares "pure" Philosophy instruction with various ways in which CT is taught in its own right:

1. Comparing (1) and (2-3): There are significant CT gains in subjects where CT is taught compared to subjects taught in pure Philosophy ($p<.05$). This suggests it is best to teach CT explicitly.
2. Comparing (1) and (2): There are no significant CT gains in subjects where CT is taught using traditional techniques (i.e., no argument mapping), compared to subjects taught in pure Philosophy ($p<0.435$). This accords with [1] above.
3. Comparing (1) and (3): There are significant CT gains in subjects where CT is taught in Philosophy using some argument mapping compared to subjects taught in pure Philosophy ($p<.01$).
4. Comparing (1) and (5): There are no significant CT gains in subjects where CT is taught as part of a non-Philosophy subject, compared to subjects taught in pure Philosophy ($p<0.272$).
5. Comparing (1) with (5) and (6): There are no significant CT gains in subjects where CT is taught as part of a non-Philosophy subject, compared to subjects taught in pure Philosophy ($p<0.806$).
6. Comparing (1) with (2) and (5): There are no significant CT gains in subjects where CT is taught

in either in or outside Philosophy subjects using traditional approaches to teaching CT compared to subjects taught in pure Philosophy ($p<.0324$).

7. Comparing (2) and (3) with (7): There are statistically significant gains when taught CT in Philosophy, compared to subjects outside Philosophy with no CT taught ($p<.01$). Again, however, these gains are not high.
8. Comparing (5) and (6) with (7): There are CT gains for subjects taught outside Philosophy, but containing some CT, compared to subjects outside Philosophy with no CT taught at all ($p<.01$).

Comparing the three salient groups where critical thinking is explicitly taught as part of a philosophy subject: 2. *Phil CT, No AM, 3. Phil CT AM,* and *4. Phil LAMP*, she finds that the standard deviations are 0.34, 0.51, and 0.78 respectively. This, to say the least, is a striking finding. It appears that teaching with argument mapping results in higher gains than teaching critical thinking in the traditional way as part of a Philosophy course, and teaching argument mapping with lots of argument mapping practice (LAMP) results in the highest gains of all.

It is clear from these findings that it is better to explicitly teach critical thinking than not to teach it at all. This may not be surprising. However, the gains expected from the teaching of critical thinking using traditional techniques as part of a philosophy course, or as part of non-philosophy subjects that aim to teach some critical thinking, are not as great as might be expected. By contrast, teaching using an argument mapping technique, and in particular, using a lots-of-argument-mapping (LAMP) approach, appears to yield much higher gains. See the tables of relative critical thinking gains in Álvarez Ortiz (2007, pp. 69-70).

3.2 Does a University Education Improve Critical Thinking Skills?

If philosophy instruction in general courses does not yield significant gains in critical thinking, there seems little hope that university training in general will produce gains. This is despite the fact that most universities boldly proclaim in their advertising documents that it does.

Indeed, there is dispiriting evidence that university study in general, does not impart significant skills in critical thinking. Larson, Britt and Kurby have found that many students leave university "unable to understand, evaluate, or write arguments" (A. A. Larson, Britt, & Kurby, 2009, p. 340). Their study, involving 57 native English-speaking students, found that college students "frequently failed to distinguish acceptable arguments from structurally flawed arguments" (p. 358). "Acceptable arguments" are ones in which a student can distinguish warranted from unwarranted arguments (i.e., supported by a reason) and to distinguish those from assertions (without any reasons at all). For example, consider the following example:

1a People should be allowed to have only two biological children

1b People should be allowed to have only two biological children because children are small

1c People should be allowed to have only two biological children because it would help stabilize population growth.

College students, it appears, could only identify warranted arguments (1c) from unwarranted arguments (1b), from assertions (1a) with only 66% baseline accuracy.

Another study involving 76 native English-speaking tertiary students found that students are "not skilled at identifying key elements of an argumentative text" and "were not proficient comprehenders of natural, written arguments" (M. Larson, Britt, & Larson, 2004, pp. 205, 220). Only 30% of all participants could identify and distinguish between *claims* (assertions) and *reasons* in a text. Most selected reasons that could not support the claims being made, and mistakenly identified counter-claims as main claims.

By far the most substantive study of recent days is the study by Arum and Roksa (2011). In a five-year study involving 2322 American college students, they report findings that 45% of students made no significant improvement in their critical thinking skills during the first two years of college and 36% made no significant improvement after an entire four-year college degree (Arum & Roksa, 2011, p. 36). Disturbing as this may be, it is consistent with Deanna Kuhn's finding that the majority of people cannot reliably exhibit skills on critical thinking under test conditions (Kuhn, 1991), and with other work on the failure of contemporary educational practices to instill critical thinking amongst students (Means & Voss, 1996; Perkins, 1985; Perkins, Allen, & Hafner, 1983).

It can be concluded from the above that doubts can be cast on the twin propositions that university in general makes any significant improvement in critical thinking skills, and studying philosophy in particular results in substantial gains in critical thinking. While studying philosophy is better than not studying it at all, the improvements made appear to be marginal.

4. Classes in Argument Mapping Do Work

I now turn my attention to evidence that instruction in argument mapping results in critical thinking gains. We have just seen from the Álvarez Ortiz metaanalysis that there is some basis for believing that LAMP, i.e., lots of argument mapping practice, results in higher critical thinking gains than taking a standard critical thinking course taught in a Philosophy department. But what is the evidence that CAAM actually improves critical thinking? There are a small, but growing, number of dedicated studies in this relatively new area of research: 1) quantitative studies; 2)

qualitative studies; and 3) mixed studies outlining both empirical and qualitative data.

4.1 The van Gelder, Bissett and Cumming Study

A paper by van Gelder, Bissett and Cumming (2004) was probably the first controlled study in this area. It evaluated the question of how people can obtain mastery of critical thinking skills, beyond competence and that level which can be obtained by maturation alone. They looked at the literature on attaining expertise and the "deliberate practice hypothesis" (DPH) as the key contemporary framework by which mastery in any area or skill is achieved (Ericsson & Charness, 1994; Ericsson, Krampe, & Tesche-Romer, 1993; Ericsson & Lehmann, 1996). The DPH is the view that expertise, is achieved by large amounts of practice of the following kind:

(1) practice is aimed at conscious improvement of a skill,
(2) practice involves regular periods of concentration of limited duration,
(3) practice involves the use of exercises which improve performance,
(4) exercises are repeated frequently in practice sessions until the desired level of expertise is attained,
(5) practice exercises are graduated in difficulty from simple to more complex, and
(6) a specialist mentor or coach provides supervision and guidance in the practice sessions.

The literature on the acquisition of expertise notes that to achieve standards beyond mere competence and approaching mastery requires, at minimum, ten years of practice of the kind described above, guided by a coach, and involving thousands of hours of deliberate practice (Ericsson & Charness, 1994; Ericsson, et al., 1993; Ericsson & Lehmann, 1996).

Van Gelder, Bisset and Cumming conjecture that critical thinking is no different from other kinds of skill (playing the piano, playing tennis, performance in mathematics), and that expertise in critical thinking requires similar conditions. If these conditions are simulated, then students will improve critical thinking beyond that expected by maturation alone. Their paper involved testing this proposition using computer-aided argument mapping (CAAM), and in particular, lots of argument mapping practice (LAMP) with CAAM, as the variable under investigation.

They conducted an empirical study to simulate these conditions involving a pre-test, post-test experimental design. The experiment involved experimental and control groups, and trials held during a full-semester course in critical reasoning at the University of Melbourne. A full-semester course is 12-weeks in the Australian context, unlike 14 weeks in the US, and with fewer contact hours per week. This experiment was conducted twice (2002 and 2003), and as the experimental design was identical, the data was combined. The number of participants in each year was 146, but owing to the need to ensure privacy screening of their computer responses, and availability for self-reports at the end of semester, this reduced the sample size and resulted in 51 usable observations in each year.

The experimental group was introduced to argument mapping, and was required to complete exercises in argument mapping during class. Students were asked to do online exercises in argument mapping after class. The online lessons comprised six tutorials on argument mapping, and twenty-four supplementary lessons. The control group was taught critical thinking in the conventional way. The number of hours spent doing argument mapping exercises on the computer were tracked by means of a computer-based counter recording the number of mouse clicks, and by means of a survey at the end of semester. These measures were compared. The measurement of critical thinking gains was achieved by two separate testing sessions using the California Critical Thinking Skills Test (CCTST), a well-validated and widely used measure of critical thinking (Facione, 1990). Note that, as the CCTST and the exercises in argument mapping conducted during and after class were substantially different in nature, any resulting gains could not be explained by "teaching to the test." As an additional measure to ensure that any resulting gains did not arise from simply doing the CCTST test twice, different tests were administered, i.e., Form A of the CCTST was administered at the start of semester and Form B was administered at the end of semester to one group, while this procedure was reversed for the other group.

Whilst the experimenters could clearly not simulate the kind of structured conditions that approximated those mentioned typical of expert performance, they did try to approach these conditions as closely as possible given the constraints of a normal semester-length university subject. In the authors' words: "[the experiment] falls short of deliberate practice as it would be experienced by elite performers in other domains" (van Gelder, Bissett, & Cumming, 2004, p. 149).

Even so, they found that there were positive relationships between the computer-recorded measures of practice, and weak to moderate positive relationships among the student self-reports. They also found that the amount of activities, and time spent practicing with the argument mapping software, were weak to moderately related to the gain in critical thinking achieved. Regression analysis showed that amount of practice predicted the gain in critical thinking.

Most surprising was the fact that the critical thinking gains in the experimental group in both cohorts (i.e., the students completing argument mapping tasks) averaged 0.8 of a standard deviation. This constituted a gain in critical reasoning—over a 12-week semester—of roughly the amount expected in an entire three- to-four year undergraduate education (van Gelder, et al., 2004,

p. 148). This was achieved in less than 100 hours of class time, and much less than the number of hours normally taught in a US-based course of a similar nature. Given that other authoritative measures of the amount of gain in critical thinking over the entire course of an undergraduate education only average about 0.50-1.0 SD, this seems surprisingly high (Pascarella & Terenzini, 1991). The gains made were also considerably higher than other documented critical thinking gains in the literature, i.e., by Lehmann (1963), and Hatcher (1999) which were roughly half of the van Gelder et. al. study. It was surmised that LAMP was the principal factor contributing to these strong gains. However, these results required further study, and replication, before any claims can be made concerning the reliability of the data.

4.2 The Twardy Study

A second study repeating the van Gelder, et al., experiment, was conducted by Twardy, who was based at a rival Australian university, but who was co-opted to trial CAAM at the University of Melbourne (Twardy, 2004). Twardy was interested to establish whether the findings in the van Gelder study were due to the "founder effect" (i.e., the originator of the method both teaching the class and conducting the experiment) and how much the gains were due to the argument mapping method practiced intensively under structured conditions.

The same experimental designed was adopted with students divided into experimental and control groups, and using a pre-test/post-test design. The total number of students in the cohort was 125, and Twardy himself took a tutorial class of nine students. The CCTST was administered twice as before, with half the students randomly receiving one version of the test, and the other half the other version. At the end of semester, this procedure was repeated. The major difference in this study was the Twardy himself was, by his own admission, unfamiliar with the CAAM method and inexperienced with the software, and gave a "poorly-taught first half of the semester"(Twardy, 2004, p. 2).

Even under these conditions, however, the experimental group results showed gains of 0.72 SD, roughly 90 percent of the gains of the previous study by van Gelder, et. al. The effect sizes of 0.7 were higher than that reported elsewhere (Donohue, Van Gelder, Cumming, & Bissett, 2002). Again, this was a significant improvement in critical thinking, as measured by an independent test, compared to other studies noted earlier. With this repeated study showing almost identical gains, it was beginning to seem as though argument mapping was a worthy new approach to the teaching of critical thinking.

4.3 The Butchart et al. Study

More recently, others have conducted a quite independent study into the use of CAAM (Butchart et al., 2009). The researchers were again based at a rival institution from the original van Gelder study mentioned above. Using the same methodology as the van Gelder, et. al., and Twardy studies, they compared critical thinking gains over a two and a half-year period (2004-2006) using a variety of different teaching methods. In each semester different teaching techniques were employed in the classroom to a cohort size averaging around 46 students. These techniques consisted of the following:

1. a course using argument mapping with automated feedback and in this instance, they used a CAAM system of their own design involving instant computer-based feedback on student responses during exercises;
2. a standard critical thinking course taught didactically in lecture-tutorial format;
3. a course taught using CAAM but without automatic, computer-generated feedback;
4. a course using a technique called "active open-minded thinking" (AOMT). This involved teaching ways of avoiding bias and weighing and considering evidence carefully, a technique attributed to Baron (1994); and
5. a course involving the use of peer instruction. The peer instruction technique involved the teacher asking multiple-choice questions at strategic moments during each class to which the students were required to respond using flash cards.

Once again, the use of CAAM was instrumental in achieving much higher gains than traditional approaches to teaching critical thinking. The results were 0.45 SD for argument mapping using automated feedback compared to 0.19 SD for the course taught using the standard didactic approach. Interestingly, peer instruction achieved nearly equivalent gains as CAAM (0.40 SD) and more than CAAM used without automatic feedback (0.22 SD). The lowest critical thinking gains were AOMT at 0.14 SD, closely followed by the course taught in the traditionally way at 0.19 SD. However, in this study it is unclear how much of the gains were due to argument mapping, and how much were confounded by other variables.

4.4 The Harrell Studies

Mara Harrell at Carnegie-Mellon University in the US has conducted a number of empirical studies quite independently of the work being done in Australia. In one recent study she trialed the effectiveness of argument mapping using a quasi-experimental design involving four tutorial groups (or "sections") of students (Harrell, 2011). Her interest was whether, given the variable initial competencies in critical thinking skills, students with lower initial ability (as measured by a pre-test) gain more from argument diagramming than students with a higher initial ability.

In the first study involving two separate experimen-

tal trials, the control and experimental groups completed an Introduction to Philosophy course after completing a test of reasoning designed to elicit their skills in critical thinking by identifying the conclusion in short passages of text. The cohort consisted on 139 students. The control groups (three separate sections comprising a total of 33 women and 71 men) were then taught the subject using traditional approaches, and not using argument diagramming. The experimental section, comprising 13 women and 22 men, was taught using argument mapping. Each class had separate lecturers and teaching assistants. Papers in the post-test were independently coded, and only students who completed both pre- and post tests were included in the analysis. Students were divided into levels depending on their pre-test scores: i.e., low, intermediate and high academic level. Results indicated both that: 1) overall, students taught argument diagramming performed better on the post test than students who did not, and 2) students in each academic level performed significantly better (for low and intermediate levels, 6.9 and 6.9 respectively, compared to 2.8 and 3.5). However, the gains in the high academic level treatment group remained about the same before and after the intervention.

Harrell conducted a repeat experiment to confirm these results and, in doing so, controlled for a number of mitigating factors that may have confounded the results. These included the size of the experimental group (which was smaller than the control groups) and the fact that the treatment group had the same lecturer for the duration of the class, while the control groups had different lecturers.

In the follow-up experiment, three separate classes comprising 21 women and 47 men formed the treatment or experimental groups, and two classes comprising 17 women and 45 men formed the control groups. This redressed the problem in the first study where there were different numbers in control and experimental groups, and in this case all classes were taught with multiple instructors. She also used modified versions of the pre- and post-test reasoning tests, and modified the tests to elicit the students' understanding of a number of facets of argumentation: conclusions or contentions, premises and reasons, and inferential connections between reasons and contentions. She also asked students to provide a graphical representation of the arguments, and state whether the arguments was "good" or "bad" and to explain their decision. In all other respects this study was the same as the pilot.

Results indicated that initial pre-test score was a statistically significant predictor of their post-test score, but that this time the average critical thinking gains were not greater in the treatment groups than the control groups (0.22 compared to 0.18). However, the post-test scores were higher for students who were in the treatment groups, compared to the control groups, and in addition, students who had the lowest pre-test scores made the highest gains in critical thinking than either the intermediate or advanced groups (0.39, compared to 0.17 and 0.10 respectively). It appears that high achieving students do not improve much from being taught argument diagramming, however students who are low achieving do. In fact, from Harrell's study, students with low critical thinking skills benefit the most from being exposed to argument diagramming techniques compared to low-achieving students exposed to traditional teaching methods. Moreover, the critical thinking gains were much higher when exposed to argument mapping over one semester than the purported gains over the course of an entire degree reported elsewhere (Pascarella & Terenzini, 2005). These results were borne out in both the pilot and main studies. Harrell has also conducted an earlier study demonstrating surprising gains, and which 'significantly raises a student's ability to analyse, comprehend, and evaluate arguments" (Harrell, 2005, p. 23).

The above studies were conducted using i*Logos,* an alternate argument mapping software. In a separate study Harrell has found that the use of computer software is incidental to the gains in critical thinking. It is not the software that appears to be making the difference, it is the activity of mapping arguments (Harrell, 2007 & 2012). However, the use of software may be responsible for additional levels of student engagement in critical thinking tasks which has been reported elsewhere (Davies, 2009).

4.5 The Carrington et al. Study

In a recent mixed methodology study by a number of authors at a Commerce Faculty, CAAM was trialed in the context of a normal subject stream in two subjects. The two subjects used for the CAAM intervention were Financial Accounting (FA) and Marketing and Society (MS), both offered in the second semester of 2009 (Carrington, Chen, Davies, Kaur, & Neville, 2011). The student cohorts were large, 109 and 182, respectively. The application of argument mapping was largely similar in each subject, involving a single, one-hour lecture on principles of argument mapping repeated to several tutorial classes. This was followed by the use of argument mapping in tutorial discussions and in some assessment tasks as part of the subjects concerned. However, there was no follow-up guidance or instruction in the use of argument mapping, nor any stipulation that computer software needed to be used. The authors were interested to know if this minimalist, "one-shot inoculation" intervention would make any difference to: a) the critical thinking abilities of students, or b) their self-perceptions of their own critical thinking skills as a result of using the argument mapping method.

The study adopted a self-reported questionnaire approach to examine the effectiveness of CAAM. The questionnaire was conducted at the end of the semester

for both the Financial Accounting and Marketing students. Analysis of the descriptive statistics from the questionnaire responses suggested that CAAM is an effective critical thinking tool. It facilitated the students' understanding process of the subject topics and subsequently helped in the write-ups of the related assignments. Further regression analysis indicates that the students valued CAAM most in the understanding of arguments. In an attempt to triangulate the results, the Marketing students were asked to complete the California Critical Thinking Skills Test (CCTST) test prior to, and following, the normal semester workload. The results of the CCTST showed significant improvement in critical thinking skills (a rise of 4.4 percent overall gain across all sub-scales) as evidenced by the higher scores achieved in the second test. This small gain is impressive given the minimalist nature of the intervention. Davies and his colleagues are presently conducting a larger-scale study involving a pre-test, post-test arrangement and using web-based instructional materials in CAAM to differentiate experimental and control groups.

4.6 The Dwyer et al. Study

Dwyer, Hogan and Stewart (2009) conducted a small-scale quantitative experiment comparing the use of argument mapping and prose in relation to memory and comprehension of reading tasks. Their participants were 400 first year psychology students aged between 17-25 at the National University of Ireland. The procedure involved an initial lecture on critical thinking for all subjects, and in the following week, they completed verbal and spatial reasoning sub-tests of the Differential Aptitude Test. Participants were then randomly assigned to one of six study conditions. These were: 1) a 30-proposition text; 2) a 30-proposition colour argument map; 3) a 30-proposition monochrome argument map; 4) a 50-proposition text; 5) a 50-proposition colour argument map; and 6) a 50-proposition monochrome argument map. Memory was tested by asking subjects to complete a fill-in-the-blanks-type task, while comprehension was tested by if a given claim was supported by a sub-set of claims of a given proposition.

Results indicated that there were significant differences in favour of monochrome and colour argument maps compared to text in terms of memory comparison on a task. In general, memory was better for coloured argument maps compared to monochrome argument maps, and for both compared to text ($p =< 0.05$ for both). Memory and recall was also better for the small representations compared with the larger ones for all treatment groups (i.e., 30-proposition as opposed to 50-proposition, i.e., $p =< 0.05$ for all three). In the case of memory, initial testing also predicted memory performance. The authors conclude that: "when compared with traditional text-based information delivery methods, argument mapping significantly increases subsequent memory for arguments" (Dwyer, Hogan, & Stewart, 2009, p. 20).

In relation to reading comprehension, there was surprisingly little evidence that argument maps improved reading performance, and little prediction of performance based on initial verbal and spatial test scores. However, the experimenters explain this as follows: "it may be that over-and-above baseline reasoning ability and spontaneous critical thinking efforts of participants, the reading of argument maps does not motivate an additional tendency to critical engage with an argument, at least not for novice maps readers. Some training in the analysis of arguments—using argument maps as study materials—may be necessary to engage students in the deeper relational analysis of maps that is necessary for good performance on tests of comprehension" (Dwyer, et al., 2009, p. 20). The Dwyer, et al. study suggests a disassociation between memory and comprehension, but it also suggests (unsurprisingly) that the advantages of argument maps in terms of memory do not necessarily translate to comprehension without substantial training in critical thinking using LAMP. This was not a deficiency of this study, however, as it sought merely to assess the impact of argument mapping on memory and reading comprehension, and argument maps did appear to improve memory performance.

4.7 Other Studies

Davies conducted a small-scale qualitative study in the context of an Economics class to ascertain students' views on the argument mapping method (Davies, 2009). The study consisted of 42 students in three separate tutorial groups. A single one-hour class on the argument mapping method, without the benefit of computers or the *Rationale*™ software, was given to each group, with instruction from the lecturer on using argument mapping to map a strand of an argument for a reading for that week's tutorial. The reading for the week was a sustained and complex argument for the settlement of Australia on economic grounds (the class was in Australian Economic History). Students submitted their argument map for assessment, which was worth 10 percent of the assessment for that subject, and the lecturer was very pleased with the resulting work, which seemed considerably clearer and more focused than previous work for that subject.

Subsequently, the students were asked to complete a survey on the argument mapping method. The students responded positively to the statement: *The material presented on argument mapping enhanced my understanding of the assessment task*, 4.29 on a 5-point Likert scale (SD: 0.642), amongst similar results for a range of other survey statements, and approximately 80 percent of students responded overwhelmingly positively to the argument mapping method in open-ended, coded feedback comments. Even though obtaining and learning how to use the software was not a requirement, the students were sufficiently engaged to learn how to use it (Davies, 2009, p. 809). Interestingly, in a separate study of a similar nature, virtually identical qualitative results

were repeated using the argument mapping software *Araucaria* (Rowe, Macagno, Reed, & Walton, 2006). A trial of the Polish version of *Araucaria* yielded similarly promising results (Budzyńska, 2011).

There is ongoing work in CAAM around the world. There are a number of studies using CAAM in legal contexts (van Driel & Prakken, 2010; van Gelder, 2007), one paper noting that argument mapping "provides some support for the hypothesis that [argument visualisation software] may be useful in increasing a judge's understanding of expert reports, and assisting him or her in asking the proper questions to the expert" (p. 7). Others have identified the value of CAAM in solving legal cases (Colen, Cnossen, & Verheij, 2009), while others have proposed alternate ways of providing argument structure based on the structure of legal topics (Schweers, 2007; Verheij, 2007).

One doctoral student in Iran is conducting a large-scale empirical study in the tertiary context that is in progress (personal communication). In a recently completed doctoral study at the University of Cyprus, a pre- and post-test experimental study was conducted on 72 elementary school students in three sixth-grade classes over a four-month period. Two experimental classes were each asked to work on argumentation activities in class, and, while one group used *Rationale*™, the other employed the argument mapping method with pencil and paper. The control group worked on argumentation activities from textbooks without any argument mapping intervention. Results indicated that there was a statistically significant increase in argumentation skills of only the group using *Rationale*™ ($t = -6{,}384$, $p = 0.001$ for $p =< 0.05$) The same author is now generalising this study to 500 sixth grade students and 22 elementary teachers (Vassiliades & Koutselini, 2012).

Another recently completed doctoral thesis conducted three separate tests and found that memory recall was better with argument maps compared to text (previously published in Dwyer, et al., 2009); they also found that participants in an argument mapping infused course scored significantly higher in tests of critical thinking (in particular in inductive reasoning); and that subjects had significantly higher critical thinking gains in verbal reasoning and argument analysis than a control group (Dwyer, 2011).

Given the apparent robustness of the data in the experimental trials just mentioned, it might seem as though there is a strong case for the use of argument mapping in teaching critical thinking. However, it is early days in an experimental sense, and there is much work to do trialing this approach in different contexts (Scheuer, Loll, Pickwart, & McLaren, 2010). This work is underway and ongoing.

Naturally there have been dissenting voices on the use of CAAM, with objections raised about the validity of the methodology used in these, and other studies (van den Braack, van Oostendorp, Parakken, & Vreeswijk, 2006). In a study examining the claims made by proponents of argument visualisation tools, noteably, *Belvedere, Convince me, Questmap* and *Reason!Able* (a predecessor of *Rationale*™), the findings were mixed. However, even these critics admit that the data from a variety of independent studies "points in the same direction," and "it is reasonable to assume that these tools have a positive effect on the users' argumentation skills" (van den Braack, et al., 2006, p. 74). If further studies bear out these findings, a consequence is that critical thinking should be taught using structured practice regimes with dedicated computer software, and not didactically using traditional approaches, as has been the case in the past.

5. What does this mean for the Teaching of Critical Thinking?

I began Part I of this paper (Davies 2012) by pointing out the three major approaches to the teaching of critical thinking: the normative or "philosophical" approach, the cognitive psychology approach, and the educational taxonomy approach. Each of them, I noted, had benefits and limitations, and drew upon a number of factors influencing the methods of instruction in the teaching of critical thinking. It may be instructive to recap each of these approaches before returning finally to argument mapping.

The normative approach is the oldest of the three major paradigms, but it still exerts a surprising hold on contemporary educational practices in the teaching of critical thinking. Many college and university courses, in western tertiary institutions at least, still use this approach. It assumes, in essence, that critical thinking is largely a feature of the well-reasoning individual; it is an idealised theory of competence, which stresses the attributes that a good critical thinker should attain, given appropriate instruction. Founded on classical roots, and educational and philosophical traditions going as far back as Aristotle's Lyceum and Plato's Academy, it emphasises *formal philosophical training* and *theoretical instruction* in logic, and allied disciplines, and stresses the importance of concerted *practice* in these areas. Focussing on the inculcation of the formal rules of classical logic and the fallacies approach to the teaching of critical thinking, amongst other things, it fails, unfortunately, on the rock of transfer. There is little empirical evidence that learning syllogisms, for example, helps much in learning to be a critical thinker in daily life. This approach neglects to pay due attention to the fact that critical thinking is not a natural activity for most people, and does not approximate how people normally think. Finally, there is little empirical evidence that this approach results in appreciable critical thinking gains when compared to other approaches. This is not to say, of course, that there are no benefits at all to learning about valid logical infer-

ences, fallacies or syllogisms. The claim is rather that this approach might well be supplemented and energised by more modern approaches that harness the intuitive appeal of the philosophical approach but which also bring advantages of a different kind.

The cognitive psychology approach, as the name suggests, is grounded in the psychological sciences. It stresses the performative aspects of being a critical thinker. This approach focuses on how people actually think under normal conditions of everyday life, and how it might be possible to expand and apply these skills to other learning domains. It assumes that competence in critical thinking arises for the situational contexts and practices inherent in the educational environment to which we expose students. On this view, we certainly learn to be critical thinkers by dedicated *practice;* but also by the evolution-primed *innate talents* we bring to the task, and the *situational context* of the learning domains to which we are exposed by our teachers. The generic ability to "think critically" is not a formally taught ability drawn merely from exposure to syllogisms, and fallacies, and practice applying and recognising these in novel contexts. It is a result of application of skills in domain-specific learning tasks that have been internalised, and then generalised and applied to other tasks within quite different learning domains. This approach lists the skills, procedures and dispositions of the critical thinker, and emphasises the importance of applying these skills. However, on the downside, it is in principle possible on this approach to follow the steps and not think critically.

The educational taxonomy approach provides a set of categories, of which Bloom's information-processing taxonomy of skills is the most notable example. It lists "comprehension" at the bottom, and "evaluation" at the top of the taxonomical hierarchy, and stresses the importance of classroom practice as the key method of instruction. But it is not clear how Bloom's categories guide instruction in critical thinking on their own, and the categories themselves are vague and imprecise.

The visualisation approach is a relatively modern approach that marshals the use of visuo-spatial tools and techniques in teaching the argument analysis component of critical thinking. Most recently this approach has utilised computer software packages (e.g., *Rationale*™, *iLogos* and *Araucaria*, amongst others), to represent inferential connections that are often not made explicit in informal reasoning. The approach claims that visualisation of reasoning aids in teaching critical thinking. This is so for a number of reasons:

- It allows off-loading of complex representational information that is hard to store in the brain given the innate limitations of human memory and concentration.
- It recognises the importance of the transparency of tacit information, and dual coding, i.e., both prose and visual forms of representation, to ensure that full advantage is made of the human cognitive apparatus.
- It maximises use of a variety of visual display techniques. This includes colours, labelling, hierarchical structuring and tiering, "umbrella" shading to show co-premises, and immediate representational accessibility (as opposed to the sequential presentation typical in prose), amongst a host of other features (see Part I of this paper, Davies, 2012). All these allow for ease of cognitive processing compared to the burden imposed by the written word when dealing with complex arguments.
- Moreover, the use of visuo-spatial displays, in the form of argument maps, constitutes greater *usability* for the person engaged in critical thinking. It is argued that this is as important a revolution as the word processor in representing thought, compared to earlier technologies such the ballpoint pen and the typewriter (van Gelder, 2007).
- Argument maps also provide a natural *complement* to an otherwise inefficient and ill-equipped cognitive system, augmenting what the brain can do, albeit imperfectly. In particular, it allows structured diagrams and statements to do the work that complex sentences and paragraphs previously had to do, allowing flexibility so the human can do further, more important, analytical work (van Gelder, 2007).
- Finally, argument maps also foster greater *semi-formality*, allowing complex inferences to be represented in the transparent and more intelligible format of natural languages, compared to the dense and far less natural representations afforded by systems of formal logic (van Gelder, 2007).

In addition, if the small number of recent empirical and qualitative studies is any guide, the visualisation approach also appears to work. Evidence seems to show that:

1. CAAM results in greater critical thinking gains compared to other approaches, as measured by a standard, well-validated tests of critical thinking (the CCTST);
2. These studies have been replicated in a number of institutions, and under a variety of educational test conditions, all appearing to show comparable gains;
3. In addition to the consistently high experimental gains demonstrated (albeit from a small number of studies), there is qualitative support. Students themselves appear to think both that their critical thinking skills have improved, and that they can see application of CAAM in areas beyond the immediate classroom. This appears to demonstrate some degree of data triangulation.

Given the demonstrated advantages of CAAM, it might seem that should be a very popular way to view the teaching of critical thinking, and may have great appeal amongst educators and philosophers alike. However, while there is historical precedent in the natural use of appropriate technologies for other purposes; for example, using

calculators to do complex mathematical problems, CAAM is still very under-utilised and under-developed. Only a few enthusiasts worldwide work with argument mapping in critical thinking courses, and there is little evidence of widespread take-up even amongst the critical thinking community. Why this is so remains a mystery to the present author.

	Factors Influencing Method of Instruction					
Approaches to Teaching Critical Thinking		Formal Training	Theoretical instruction	Situation cognition	Practice	Evolutionary Psychology
	Normative approach	■	■		■	
	Cognitive-Psychology approach			■	■	■
	Educational approach				■	
	Visualisation approach	■	■	■	■	■

6. The Methods of Instruction in Teaching Critical Thinking: An Overview

As we have seen, the other approaches to the teaching of critical thinking variously emphasise practice, formal instruction, situated cognition, and evolutionary psychology as important influences on the method of critical thinking instruction. What are the factors influencing the methods of instruction on the visualisation approach?

In the visual approach adopted, a number of influences predominate. *Practice* is clearly a key requirement, as is *formal instruction* in argument mapping methodology. As discussed earlier, the LAMP approach, and the deliberative practice hypothesis, emphasises the critical importance of workshop activities where argument mapping is practiced under supervision, and where mapping exercises are graded and graduated, eventually building to greater levels of expertise.

Moreover, the visualisation approach is cognisant of *situated cognition*. It is recognised that practical activities should be situated in context and in a variety of learning domains. Rather than evaluating stock syllogisms and fallacies, which is the basis of the philosophical approach, the visualisation approach emphasises that "real" arguments, expressed in authentic prose, be considered objects of analysis, discussion and evaluation. Discipline-based arguments should also be considered once the basics of argument mapping are clear to students and they have gained a modest degree of proficiency.

Finally, the visualisation approach pays due attention to the innate limitations of human cognition and principles of evolutionary psychology (Cosmides & Tooby, 2013), with explicit recognition that the brain requires augmentation by means of a dedicated tool for the purpose of representing arguments in visual form. While practice is emphasised over theory and formal training in CAAM, the visualisation approach sees all influences on method of instruction as being important contributing factors. I believe that this makes the visualisation approach to critical thinking a richer, and broader approach; one which is cognisant of the various factors relevant to teaching of critical thinking than the other approaches outlined in this paper. This is summarised in the table above.

7. Conclusion

This paper discussed the three traditional approaches to the teaching of critical thinking, and the factors influencing the methods of instruction adopted by each approach. The paper presented an alternative approach, the visualisation approach, focusing on computer-aided argument mapping, or CAAM (using *Rationale*™) as an exemplar of this approach. The paper documented the methodology, the design principles, and the CAAM pedagogy. The paper also outlined the arguments and evidence for the effectiveness of CAAM, concentrating on the empirical data demonstrating solid gains in critical thinking using CAAM, but also mentioning the theoretical support, and reflections of the students using both the CAAM approach and the *Rationale*™ software. Finally, the paper compared the four main approaches to the teaching of critical thinking, noting that the visualisation approach adopts all the main influences on the method of instruction, resulting in it being a broader, more embracing, approach to the teaching of critical thinking.

It remains to recommend the visualisation approach, in the guise of computer-aided argument mapping, as a viable approach for instructors. Given the paucity of evidence that university education improves critical thinking skills, and the laudable aim of improving the critical thinking skills of students (thereby equipping them for the challenges of the twenty-first century), new approaches are clearly needed. CAAM may well be an approach whose time has come.

References

Alvarez Ortiz, M. Claudia (2007). *Does Philosophy Improve Critical Thinking Skills?* Unpublished Masters Thesis, University of Melbourne, Melbourne.

Arum, R., & Roksa, J. (2011). *Academically adrift: Limited learning on college campuses.* Chigago, IL: University of Chicago Press.

Baron, J. (1994). *Thinking and Deciding*. Cambridge: Cambridge University Press.

Budzyńska, K. (2011). Araucaria-PL: Software for Teaching Argumentation Theory. In P. Blackburn, H. v. Ditmarsch, M. Manzano & F. Soler (Eds.), *Proceedings of the Third International Congress on Tools for Teaching Logic (TICTTL 2011)* (pp. 30-37): LNCS, LNAI-FOLLI series (6680), Springer-Verlag.

Butchart, S., Forster, D., Gold, I., Bigelow, J., Korb, K., & Oppy, G. (2009). Improving Critical Thinking Using Web-based Argument Mapping Exercises with Automated Feedback. *Australasian Journal of Educational Technology, 25*(5), 268-291.

Carrington, M., Chen, R., Davies, M., Kaur, J., & Neville, B. (2011). Enhancing Critical Thinking: The Effectiveness of a Single Intervention of Computer-Aided Argument Mapping in a Marketing and a Financial Accounting Subject. *Higher Education Research and Development, 30*(3), 387-402.

Colen, S., Cnossen, F., & Verheij, B. (2009). *How Much Logical Structure is Helpful in Content-Based Argumentation Software for Legal Case Solving?* Paper presented at the The 12th International Conference on Artificial Intelligence and Law. Proceedings of the Conference. Retrieved from http://www.ai.rug.nl/~verheij/publications/icail2009.htm.

Cosmides, L. & Tooby, J. (2013). Evolutionary psychology: New perspectives on cognition and motivation. *Annual Review of Psychology, 64*, 201-229.

Davies, M. (2009). Computer-Assisted Argument Mapping: A Rationale Approach. *Higher Education, 58*(6), 799-820.

Davies, M. (2012) Computer-Aided Argument Mapping and the Teaching of Critical Thinking: Part I. *INQUIRY: Critical Thinking Across the Disciplines,* 27(2,15-30.

Donohue, A., Van Gelder, T., Cumming, G., & Bissett, M. (2002). *Reason! Project Studies 1999-2002* (No. 2002/1). Melbourne: University of Melbourne.

Dwyer, C. P. (2011). *The Evaluation of Argument Mapping as a Learning Tool.* National University of Ireland, Galway.

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2009). The Evaluation of Argument Mapping as a Learning Tool: Comparing the effects of Map Reading versus Text Reading on Comprehension and Recall of Arguments. *Thinking Skills and Creativity, doi:10,1016/j.tsc.2009.05.001*.

Ericsson, K. A., & Charness, N. (1994). Expert Performance. *American Psychologist, 49*, 725-747.

Ericsson, K. A., Krampe, R. T., & Tesche-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*, 363-406.

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: evidence of maximal adaptation to task constraints. *Annual Review of Psychology, 47*, 273-305.

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction*. Millbrae, CA: The California Academic Press.

Harrell, M. (2005). *Using Argument Diagrams to Improve Critical Thinking Skills in 80-100 What Philosophy Is*. Pittsburgh, Pennsylvania: Carnegie Mellon University.

Harrell, M. (2007). No Computer Program Required: Even Pencil-and-Paper Argument Mapping Improves Critical Thinking Skills. *Teaching Philosophy, 31*(4), 351-374.

Harrell, M. (2011). Argument diagramming and critical thinking in introductory philosophy. *Higher Education Research and Development, 30*(3), 371-385.

Harrell, M. (2012). Assessing the Efficacy of Argument Diagramming to Teach Critical thinking Skills in Introduction to Philosophy. *INQUIRY: Critical Thinking Across the Disciplines*, 27(2), pp. 31-38.

Hatcher, D. L. (1999). Why Critical Thinking Should be Combined with Written Composition. *Informal Logic, 19*, 171-183.

Kuhn, D. (1991). *The Skills of Argument*. Cambridge: Cambridge University Press.

Larson, A. A., Britt, M. A., & Kurby, C. A. (2009). Improving Students' Evaluation of Arguments. *The Journal of Experimental Education, 77*(4), 339-365.

Larson, M., Britt, M. A., & Larson, A. A. (2004). Disfluencies in Comprehending Argumentative Texts. *Reading Psychology, 25*(3), 205-224.

Lehmann, I. J. (1963). Changes in Critical Thinking, Attitudes and Values from Freshmen to Senior Years. *Journal of Educational Psychology, 54*, 305-315.

Means, M. L., & Voss, J. F. (1996). Who Reasons Well? Two Studies of Informal Reasoning Among Children of Different Grade, Ability and Knowledge Levels. *Cognition and Instruction, 14*, 139-178.

Pascarella, E., & Terenzini, P. (1991). *How College Affects Students*. San Francisco, CA: Jossey-Bass.

Pascarella, E., & Terenzini, P. (2005). *How College Affects Students*. (Vol. 2. A Third Decade of Research). San Francisco, CA: Jossey-Bass.

Perkins, D. N. (1985). Primary Education has Little Impact on Informal Reasoning. *Journal of Educational Psychology, 77*, 562-571.

Perkins, D. N., Allen, R., & Hafner, J. (1983). Difficulties in Everyday Reasoning. In W. Maxwell & J. Bruner (Eds.), *Thinking: The Expanding Frontier*. Philadelphia: The Franklin Institute Press.

Rowe, G., Macagno, F., Reed, C., & Walton, D. (2006). Araucaria as a Tool for Diagramming Arguments in Teaching and Studying Philosophy. *Teaching Philosophy, 29*(2), 111-124.

Scheuer, O., Loll, F., Pickwart, N., & McLaren, B. M. (2010). Computer-Supported Argumentation: A Review of the State of the Art. *International Journal of Computer-Supported Collaborative Learning, 5*(1), 43-102.

Schweers, M., & Verheij, B. . (2007). *Beyond Boxes and Arrows: Argumentation Support in Terms of the Knowledge Structure of a Legal Topic*. Paper presented at the Legal Knowledge and Information Systems. Jurix 2007: The Twentieth Annual Conference. Retrieved from http://www.ai.rug.nl/~verheij/publications/jurix2007.htm.

Twardy, C. (2004). Argument Maps Improve Critical Thinking. *Teaching Philosophy, 27*(2), 95-116.

van den Braack, S., van Oostendorp, H. v., Parakken, H., & Vreeswijk, G. A. (2006, 28-29 August). A Critical Review of Argument Vizualisation Tools: Do Users Become Better Reasoners? Paper presented at the ECAI-06 Workshop on Computational Models of Natural Argument, Riva del Garda, Italy.

van Driel, S., & Prakken, H. (2010). Visualising the Argumentation Structure of an Expert Witness Report with Rationale (extended Abstract). Paper presented at the Proceedings of the Workshop on Modelling Legal Cases and Legal Rules, in conjunction with JURIX-10. Retrieved from http://www.cs.uu.nl/groups/IS/archive/henry/wscases10.pdf.

van Gelder, T. (2007). The Rationale for Rationale™. *Law, Probability and Risk, 6*, 23-42.

van Gelder, T., Bissett, M., & Cumming, G. (2004). Cultivating Expertise in Informal Reasoning. *Canadian Journal of Experimental Psychology, 58*(2), 142-152.

Vassiliades, Y., & Koutselini, M. (2012). *Development of Critical Thinking in Students of Elementary School through Argumentation with the Use of Computers.* University of Cyprus, Nicosia.

Verheij, B. (2007). Argumentation Support Software: Boxes-and-Arrows and Beyond. *Law, Probability & Risk, 6*, 187-208.

Author Information

Martin Davies is an Associate Professor in Higher Education and Honorary Research Fellow in Economics in the Faculty of Business and Economics at the University of Melbourne. He is a former Co-Editor, and Guest Editor, of the journal *Higher Education Research and Development* and a member of AILACT. He is currently working with Ron Barnett and Robert H. Ennis on an edited collection of papers for a book entitled *Critical Thinking in Higher Education*. He has no commercial interest whatsoever in the development or sale of the software *Rationale*™. Contact: wmdavies@unimelb.edu.au.