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# The Experience of Using a Cognitive Acceleration Approach with Prospective Primary Teachers from Three Chilean Universities

# La experiencia de usar un programa de aceleración cognitiva con futuros profesores de tres universidades chilenas

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## Abstract

Cognitive Acceleration (CA) programs have been used successfully in the UK and in other countries to promote the development of what Piaget called formal reasoning skills in school students for the last 30 years. Given that the approach has had a tremendous impact on the thinking capabilities of participating students, this study explored the impact of using the program with prospective primary teachers in three Chilean universities. To assess the impact this program had on prospective teachers' formal reasoning skills, this study used a quasi-experimental design where experimental students were compared with control counterparts in terms of their performance on the Science Reasoning Task test at the beginning and at the end of the intervention. The main findings indicate that, at the end of the Cognitive Acceleration course, prospective teachers from the experimental group demonstrated higher reasoning levels than their peers that did not participate in the program.

***Keywords:*** cognitive acceleration, formal reasoning skills, prospective teachers, initial teacher training

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## Resumen

Los programas de Aceleración Cognitiva (CA) se han utilizado con éxito durante los últimos 30 años en el Reino Unido y en otros países para promover en estudiantes escolares el desarrollo de las habilidades de razonamiento formal descritas por Piaget. Debido a que este tipo de programas ha tenido un gran impacto en las habilidades de razonamiento de los estudiantes que han participado en ellos, este estudio exploró el impacto de usar este mismo programa pero con estudiantes de pedagogía básica de tres universidades chilenas. El estudio contó con un diseño cuasiexperimental con un grupo experimental y un grupo de control por cada universidad participante, y los cambios en las habilidades de razonamiento formal se midieron a través de un test de razonamiento científico al inicio y al término de la intervención. Los resultados del estudio indican que el grupo experimental al final del programa de aceleración cognitiva mostró mayores niveles de razonamiento formal que sus compañeros que no participaron.


***Palabras clave:*** aceleración cognitiva, habilidades de razonamiento formal, futuros profesores, formación inicial docente

In modern society, knowledge exchange plays a major role and the globalized era has posed new challenges for current education systems. Consequently, the educational goals pursued some decades ago need to be changed to accommodate both new and novel ways of improving the schooling process of future generations. A group of scholars has agreed that one of these new educational aims is the development of thinking skills (Barak & Dori, 2009; Preiss & Sternberg, 2006; Torff, 2003). For this reason, teachers need to change their focus from teaching the content of subjects to the promotion of complex cognitive skills that encourage students to become independent and active learners.

Since Jean Piaget and Inhelder (1958) developed their cognitive model, it has traditionally been understood that types of thinking that are more complex are usually acquired during adolescence (Anderson, Reder, & Simon, 1996). However, the body of research on cognitive development conducted over the last three decades, has shown that a significant proportion of secondary school students (Adey & Shayer, 1994; Shemesh, Eckstein, & Lazarowitz, 1992; Valanides, 1997a, 1997b), university students (Niaz, 1985; Reyes, 1987) and prospective teachers (Brownell, Jadallah, & Brownell, 1993; Silverman & Creswell, 1982; Wyatt, 1983) have not yet developed these abilities. In this context, in the UK Shayer and Adey (1981) decided to design a cognitive acceleration (CA) program for school students that could reverse this situation. Therefore, they created a set of thinking activities that were used once every two weeks instead of ordinary lessons in order to promote and enhance the students' general thinking abilities, which could then be transferred to other tasks, situations, or domains.

Throughout the 1980s, Michael Shayer and Philip Adey investigated how well their CA program worked in a number of schools, using a quasi-experimental design. The intervention was considered successful because the students assigned to the experimental condition showed statistically greater cognitive development after the program than their control counterparts. In addition, the authors found that the intervention also had a long-term and far-transfer effect. Although the intervention was set in a science context and was conducted by science teachers, students assigned to the experimental condition obtained better results not only in science, but also in national mathematics and English tests. Since CA produced such promising results in science, CA programs began to be developed for other school subjects (Adhami, Johnson, & Shayer, 1998; Adhami, Shayer, & Twiss, 2005; Shayer & Adhami, 2003), in accordance with students' ages (Adey, Robertson, & Venville, 2001, 2002; Adey & Shayer, 2002; Adhami et al., 2005; Shayer & Adhami, 2003) and in different countries (Endler & Bond, 2008; Iqbal & Shayer, 2000; Mbano, 2003).

For this reason, this study aimed to develop a Cognitive Acceleration course within the context of initial teacher training in order to explore the impact that such a learning experience would have on the formal reasoning skills of prospective teachers.

## Literature review

### Jean Piaget and his epistemological theory

Jean Piaget and his colleagues were among the first to use the term 'formal reasoning skills' and to describe the processes whereby cognitive structures are developed (Anderson, 2003). This work is mainly based on the Piagetian concept of formal thinking skills, which is why Piaget's theory and epistemology will be described in this section.

Piaget (1972) identified the sequence of stages through which intellectual structures advance in every child. However, that does not mean that each person's structures move from one stage to the next at the same time or at the same age. While the sequence is predetermined, the speed of each person's progress is influenced by an immense variety of factors that make each individual's progress unique.

The last and most complex stage described by Piaget is the formal operational stage, which is reached during adolescence at about 14-15 years old. He stated: "The principle novelty of this period is the capacity to reason in terms of verbally stated hypotheses and no longer merely in terms of concrete objects and their manipulation" (Piaget, 1972, p. 42). This change is a very important one, because the universe of reasoning becomes independent of the real world. The adolescent is now able to think in terms of what could be possible and not only about what it is real which, in turn, makes him or her capable of anticipating the consequences of a hypothetical premise without necessarily judging its truthfulness or falseness. All these changes produce qualitatively relevant progress in the social sphere. Hypothetical reasoning transforms others' points of view into arguments that can be understood and evaluated in terms of the consequences that can logically be deduced from them. This does not necessarily mean that adolescents have to share others' opinions, but they can now think about and discuss them with others.

Arriving at this last stage implies that the person is now able to perform the ten qualitatively different formal operations described by the authors: combinatorial thinking, control of variables, exclusion of irrelevant variables, coordination of frames of reference, notions of probability, notions of correlation, multiplicative compensation, equilibrium of physics systems involving three or more variables, proportional thinking, and physical conservation involving models (Piaget & Inhelder, 1958).

### The role cognitive acceleration programs have played in promoting formal reasoning skills

The stimuli present in the child's environment play a crucial role in his or her cognitive development by challenging the current cognitive structures and by forcing the child to adapt to new and more complex organizational forms (Piaget, 1964). Accepting this statement could lead to the understanding that the teacher's role is to be in charge of placing or presenting the correct stimuli to promote the students' reasoning ability. The key characteristic of these stimuli is that they have to be sufficiently challenging to produce the necessary cognitive instability.

During the early 1980s, this assumption encouraged Shayer and Adey (1981) to develop the first Cognitive Acceleration project, namely Cognitive Acceleration through Science Education (CASE). In general terms, the program consisted of creating and using different thinking activities instead of ordinary science lessons in order to promote and enhance students' thinking abilities in terms of the type of thinking that Piaget called 'formal operations'. Although the literature describes a wide range of cognitive acceleration initiatives (Case, 1974; Feuerstein, Rand, Hoffman, & Miller, 1980; Kuhn, Ho, & Adams, 1979; Kuhn & Angelev, 1976; Lawson & Blake, 1976; Lawson & Nordland, 1976; Lawson & Snitgen, 1982; McGuinness, 2000; Panizzon & Bond, 2007; Rosenshine, 1992; Rosenthal, 1979; Siegler, Liebert, & Liebert, 1973), very few of them lasted more than two months and had the purpose of training general thinking abilities that could be transferred to other tasks, situations, or domains.

Given that the CASE program was so successful (Adey, 2005) in promoting formal reasoning skills in school students, new Cognitive Acceleration programs started to be developed in other school subjects (Adhami et al., 1998; Adhami et al., 2005; Shayer & Adhami, 2003), with students of different ages (Adey, Robertson, & Venville, 2001, 2002; Adhami et al., 2005; Shayer & Adhami, 2003), and in various countries (Endler &

Bond, 2008; Iqbal & Shayer, 2000; Mbano, 2003). As a result, while the CASE project has been implemented since the 1980s, Cognitive Acceleration in Mathematics Education (CAME) was delivered for the first time in 1993. The original intention was to foster cognitive development in secondary school students who were 11 to 14 years-old or, in other words, to encourage students to think mathematically (Shayer, Johnson, & Adhami, 1999). The relevance of developing a project with that purpose was similar to the objective of CASE in its early stages; the understanding that a large part of the mathematics school curriculum requires the use of formal reasoning skills in order to comprehend it in-depth, and the evidence showed that only 20% or 30% of 14 year-old students had already developed these reasoning skills (Shayer & Adhami, 2007).

To accomplish these objectives, the CAME project provides a set of 30 activities designed to be carried out four or five times each school term over a two-year period. Each activity requires that students organize conceptual strands in mathematics instead of using just procedures and algorithms as they would do in 'normal' mathematics lessons. In other words, rather than promoting a mechanical or memory-based method of solving problems, CAME attempts to develop reasoning skills thorough the process of requiring students to reconstruct the underlying mathematical concepts and the reasons for them (Adhami et al., 1998).

### CAME lessons and their impact

CAME lessons are based on collaborative activities that utilize dialogue to stimulate and promote high-order thinking. Each CAME activity lasts between 60 and 90 minutes and the teacher acts as a mediator during group and class exchanges. In this sense, although each CAME activity uses mathematical concepts to promote students' thinking skills, the lessons do not deal with them directly by demonstrating the concepts, but indirectly through individual, small group, or whole-class work. Given the particular characteristics of CAME activities, they are not intended to substitute regular school lessons but to complement them, since students are given the opportunity to both learn and investigate at the same time.

Given the variety of abilities present in every classroom, CAME activities are intended to adapt to students who are performing at two or three different levels. In other words, this feature allows challenges to students' current assumptions and therefore promotes learning even if they have different developmental levels.

As regards the structure of the lesson, activities at the beginning introduce a familiar context in order to make sure that all students have the necessary background to understand and develop the other parts of the lesson. Students then work on some of the mathematical problems that CAME provides. In order to solve these challenges, students need to accommodate their thinking patterns to higher levels. This may not happen spontaneously, so CAME teachers will have to guide students through the problem by raising questions that encourage students to solve it (Adhami et al., 1998).

During the first two years of the CAME project, three schools participated in the piloting and design of the lessons. In each school, one class was taught by the head of the mathematics department. After the first two years of the trial, 11 schools were chosen to participate and all of their Year 7 students took part in the study. The researchers divided the schools into three groups (Shayer & Adhami, 2007):

i. 'Core' schools, which had experimental classes and their teachers received frequent, in-school training from the research team.
ii. 'Attached' schools, which also had experimental classes, but their teachers had to attend training sessions held at King's College London.
iii. Control classes.

In order to assess the impact of CAME, all the students from the experimental and control classes took a mathematics test at the beginning (pre-test) and at the end (post-test) of the two-year intervention. In addition, in order to evaluate the transferability and permanence of the impact, students' results on the General Certificate of Secondary Education (GCSE) for maths, science and English at the end of Year 11 were included in the study (Shayer & Adhami, 2007).

As Table 1 shows, the results obtained by the experimental classes immediately after the intervention were not very impressive in terms of the magnitudes of the effect. However, when the data from the control groups and from the GCSE exams are included, the picture changes (see Figure 1). To calculate the value added by CAME in terms of GCSE grades, each experimental school's mean grade in the GCSE is plotted against the mean obtained by the same school in the pre-test taken at the beginning of Year 7. Similarly, the regression line for control schools is drawn based on their GCSE grades. Consequently, the distance between the regression line and each school's mean is the value added by CAME to GCSE grades (see Figure 1) (Shayer & Adhami, 2007).

Table 1
Pre- and post-test school means on the math test

| | | Post-test | | | |
|---|---|---|---|---|---|
| School | Pre-test | Predicted | Obtained | Effect (SD) | P |
| Core 1 | 6.08 | 6.49 | 7.00 | 0.41 | <.01 |
| Core 2 | 5.32 | 5.79 | 6.02 | 0.18 | <.05 |
| Core 3 | 5.03 | 5.52 | 5.66 | 0.13 | n.s. |
| Core 4 | 5.45 | 5.91 | 6.47 | 0.52 | <.01 |
| Attached 1 | 5.63 | 6.08 | 6.58 | 0.49 | <.01 |
| Attached 2 | 5.99 | 6.41 | 7.02 | 0.56 | <.01 |
| Attached 3 | 4.77 | 5.29 | 5.59 | 0.28 | <.01 |
| Attached 4 | 5.69 | 6.13 | 6.15 | 0.01 | n.s. |
| Attached 5 | 5.30 | 5.78 | 6.17 | 0.38 | <.01 |
| Attached 6 | 5.29 | 5.77 | 5.97 | 0.2 | <.025 |
| Attached 7 | 5.68 | 6.13 | 6.76 | 0.62 | <.01 |
| Overall mean | | | | 0.344 SD | |

Note: Source Shayer & Adhami, 2007, p. 278.

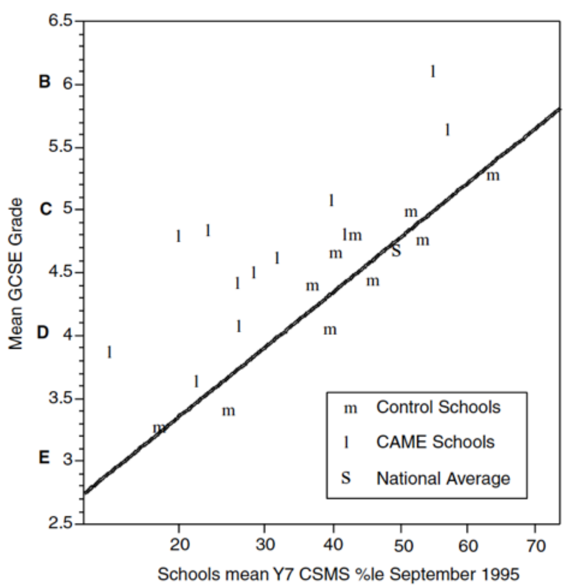


Figure 1. Added Value in GCSE 2000 maths for CAME schools. Source Shayer & Adhami, 2007, p. 280.

## Methods

Even though CA programs have been used in various countries since the 1980s, this was the first time that this approach was delivered with prospective teachers or, in other words, undergraduate students instead of school students. In this context, the purpose of the study was to explore the impact of using the CAME approach on prospective teachers' formal reasoning skills.

### Research design

The study had one experimental and one comparison group for each participating university in order to explore whether it was possible to observe differences between them in terms of their ability to think formally after the intervention group participated in the CAME course. Given that it was not possible to randomly allocate participants to one of the two experimental conditions (experimental or comparison), the study used a quasi-experimental design.

The research was planned considering that a university semester in Chile lasts for 5 months or 18 weeks. For that reason, the first and the last week were evaluative because a formal reasoning test was administered as a pre- and post-test to the experimental and the comparison group. As a result, during the other 16 weeks the proper intervention was delivered, consisting of a different CAME lesson each week.

Table 2
Data collection time-frame and research techniques

| Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Formal Reasoning Test | | | | | | | | | | | | | | | | | | |
| CAME Lessons | | | | | | | | | | | | | | | | | | |

### The sample and the sampling process

The specific sampling method used by the study was intentional cluster sampling (Hesse-Biber, 2010), whereby the smallest eligible unit was Faculties of Education and not individual students. This type of method had the advantage of selecting universities that could be good representatives of the variety of higher education institutions that exist in Chile, and in ensuring that participating universities were committed to the project, because all the sessions were going to be developed in their lecture rooms during term time and they had to provide all the necessary materials (blackboards, pens, photocopies, and so on). Therefore, it was essential that Faculties of Education were engaged in the project in order for them to facilitate such resources.

Even though the sampling process had the aforementioned advantages, it also had the drawback of generating samples composed of smaller groups (clusters) that, in turn, were composed of individuals who shared certain characteristics. For example, the participants who are studying at the same university are likely to have similar academic backgrounds, because each university has specific entry requirements. This makes it difficult to ensure that the sample selected is representative of the population; that is to say, that the individuals included in the sample are a good illustration of the variety present in the general population (Cohen, Manion, & Morrison, 2007).

Three Faculties of Education took part in this research. For confidentiality reasons, they will be indicated as follows: (i) UA, (ii) UB, and (iii) UC. Only three universities were selected to participate in the study, mainly for reasons of feasibility. All of the CAME lessons were delivered by the research team and, in this context, three was a large enough number to ensure variability within the sample, while still being small enough to be manageable. Even though all the participating universities were private, the profile of the students they accept is quite diverse, especially in terms of previous academic achievement and the kind of school they attended (see Table 3). However, given the small number of universities participating in the study, it is not possible to consider the sample as being representative of the whole population.

Table 3
Characterization of participating universities

| University | Selectivity level % | % of students that come from each type of school | | |
|---|---|---|---|---|
| | | Private | Subsidized | Public |
| UA | 57 | 92 | 6 | 2 |
| UB | 24 | 67 | 25 | 7 |
| UC | 1.25 | 2 | 43 | 55 |

After obtaining permission to work at the three universities, individual students were recruited to take part in the course. In this regard, even though the universities had agreed to be part of the project, the students were completely free to choose whether or not to participate. The fact that the students voluntarily attended the course might imply that the sample was biased in the sense that it did not represent the entire population of students at that university. In other words, it is likely that the sample was probably composed of students who were more motivated or students that had a particular interest in participating in the course. Even though this is a disadvantage for the explanatory potential of the CAME course, for ethical reasons it was not possible to select the participants randomly.

Table 4
Students registered for the course

| | UA | UB | UC | TOTAL |
|---|---|---|---|---|
| No. students in the 1$^{st}$ session | 24 | 11 | 10 | 45 |

To recruit individual students, an email was sent to the secretaries of the Faculties of Education and they forwarded the invitation to the potential participants. As a response to that invitation, a group of students from each university registered for the course (see Table 4). However, only a group of them actually participated, which means that they attended at least 80% of the CAME sessions. In this regard, those students who attended 80% of the sessions were considered as the experimental group and those who registered their interest in the course but did not attend the CAME sessions, only attending the first session and therefore taking the SRT test at the beginning and at the end of the semester, were considered as the control group (see Table 5). Finally, Table 6 shows the gender and age distribution of the sample.

Table 5
Participating students per university

| | UA | UB | UC | TOTAL |
|---|---|---|---|---|
| Experimental | 14 | 8 | 4 | 26 |
| Comparison | 4 | 8 | 3 | 15 |
| TOTAL | 18 | 16 | 7 | 41 |

Table 6
Characterization of experimental and comparison group

| | Experimental | Comparison |
|---|---|---|
| Male | 1 | 4 |
| Female | 25 | 11 |
| Average age | 23.2 | 22.9 |

**Measuring formal reasoning skills: The Science Reasoning Task (SRT) Test**

The Science Reasoning Task (SRT) test was used as a pre- and post-intervention test, with the intention of exploring whether it was possible to observe changes in terms of measured formal reasoning skills in the research participants.

Even though there is a wide range of tests that pursue the purpose of measuring formal reasoning skills (Arlin, 1982; Carlson, Dalton, & Fagal, 1977; Lawson, 1978; Lawson, Nordland, & Devito, 1975; Roberge & Flexer, 1982; Rowell & Hoffman, 1975; Shayer, Adey, & Wylam, 1981; Tobin & Capie, 1981), the SRT test was selected, not only because is the test that has always been used for assessing the impact of each CA intervention (Adey et al., 2002; Adey & Shayer, 1990, 1994, 2002; Adhami, Johnson, & Shayer, 1997; Shayer, 1996; Shayer & Adhami, 2006, 2007; Shayer, Johnson, & Adhami, 1999), but also because it has been more rigorously validated (Shayer et al., 1981).

Of the seven existing reasoning tasks, Task II: Volume and Heaviness was chosen for two main reasons. Firstly, it covers the entire range of thinking stages described by Piaget; thus, it allows the classification of the evaluated person from the early concrete stage (2A) to the mature formal operational stage (3A) (see Table 7). In addition, the Volume and Heaviness task has been widely used for the purpose of evaluating formal reasoning skills in different age samples and in different contexts (Budiman, Halim, Meerah, & Osman, 2009; Hautamäki, 1986; Howe & Shayer, 1981; Kutnick & Thomas, 1990; Lim, 1988, 1994; Maume & Matthews, 2000; McCormack, Finlayson, McCloughlin, & CASTeL, 2010; Prophet & Vlaardingerbroek, 2003; Rogan & MacDonald, 1983; Shayer, Kuchemann, & Wylam, 1976; Shayer & Wylam, 1978; Sprod, 1998), which is highly relevant considering that this study planned to use the test with an older population and in a language other than English.

It is important to state that the other advantage of using the SRT test for evaluating the formal reasoning level of the experimental and comparison group, at the beginning and end of the intervention, is that is a multiple choice format test with only one correct answer. This implies that the test administration and correction process are standardized and rigorous in order to ensure validity of the results. As a consequence, each person is classified into one of five reasoning levels (from concrete to mature formal) depending on the number of responses they get correct and the difficulty level of the answers, which is determined in the scoring rules of the administration protocol.

Table 7
Classification of reasoning level

| Classification | Reasoning level |
|---|---|
| 2A | Early concrete |
| 2A/2B | Concrete |
| 2B | Mature concrete |
| 2B/3A | Early formal |
| 3A | Mature formal |

Note: Source Shayer, 1977.

**The selection, adaptation, and implementation of CAME activities**

The number of activities selected was guided by the number of weeks (18) that constitute a semester in Chile. As a result, the plan for the course included 16 CAME lessons and two evaluative lessons, one at the beginning and one at the end of the course. In addition, in order to decide which of the 30 CAME activities would be included in the course, three criteria were taken into consideration:

i. The appropriateness of the activities for the group of students in the study, not only in terms of age, but also in terms of characteristics. In order to fulfil this criterion, the role of a pilot study that tested out the activities one year before the main study was crucial.
ii. The coverage of the six different strands that are included in CAME lessons (Number system and properties, Multiplicative relations, Functions, Algebra models, Shape and Space, and Data handling).
iii. The inclusion of activities with different difficulty levels based on the Piagetian levels described by each activity. It was important to cover the entire range of Piagetian levels because, in the pilot, it was already identified that prospective teachers had different levels of formal reasoning skills; thus, some of them were operating at the concrete level and others at the formal level.

After selecting the activities, the next phase consisted of adapting them to the appropriate context. It is important to note that the adaptation process did not finish when the entire course was designed and planned before the beginning of the term. In contrast, the adaptation process was iterative in the sense that, based on the experience and results of previous activities, the following ones were adapted continuously.

**Ethics**

As the CAME course was offered as one of the optional courses that prospective teachers could take during the semester, it was very important for the students to understand the difference between participating in the course and participating in the research project. Even though some of them were not interested in taking part in the research, they were still allowed to take the course. In order to explain this, they were given an information sheet during the first session that stated that the course was part of a research project and that voluntary participation in it involved (i) answering a multiple-choice and open-ended question test at the beginning and at the end of the course and (ii) attending 16 CAME sessions (one each week for 16 weeks).

It was also explained to prospective teachers that their participation in the research was purely voluntary. For that reason, in the information sheet it was also explained that they were free to choose not to answer the test questions or to attend the CAME sessions. They also had the right to leave the course or the research project at any time and to withdraw all their information from the study before November 2012, when the data analysis stage was scheduled to begin. Apart from accepting the terms stated on the information sheet, they had to sign a consent form in order to formalize their agreement to participate in the project. Both documents clearly stated that they had the right to withdraw their participation before November 2012 without experiencing any consequences.

Some students who were contacted and invited to participate did not agree to take part in the study. However, attendance of individuals was not disclosed to university tutors. Student teachers who participated solely in the formal reasoning test (control group) also had the right to withdraw their participation at any point before November 2012; a date that was also clearly stated on the information sheet and consent form.

The confidentiality of the participants in the formal reasoning test was assured by not disclosing the results to any university authority or tutor, and the data were kept in files secured by a key to which only the research team had access. Since the SRT test was measuring their formal reasoning abilities, their results of the tests were not disclosed and they did not have access to the test answers either. Finally, the information sheet also stated that all the data was to be used only once and for the purposes described in the consent form. Therefore, if the research team wanted to use that data again in the future, they would have to ask the individuals to re-consent.

### Data analysis

The volume and heaviness task (task II from the SRT test) consists of a group of 14 questions, each of which is classified according to five categories, from early concrete (2A) to mature formal (3A), based on the reasoning level they require. In turn, each person's performance is classified according to one of those five categories (from 2A to 3A), depending on the combination of questions and the difficulty level of the questions that they answered correctly.

Following the corresponding scoring rules, the 41 participants (26 in the experimental and 15 in the comparison condition) were classified according to those five categories of reasoning level for the pre- and post-tests. For that reason, the statistical analysis conducted corresponded to non-parametric tests since the data was ordinal and not ratio and the sample size was small. Specifically, the five reasoning level categories that resulted from the application of each of the SRTs were ordered from 1 (2A: lowest reasoning level) to 5 (3A: highest reasoning level). Therefore, two Mann-Whitney U tests that are specifically designed to deal with ordinal data were run.

## Results

### Change in prospective teachers after the CAME course: Descriptive results

At the beginning of the CAME course 69.23% of the experimental group and 40% of the comparison group showed some level of formal reasoning. In turn, when the CAME course was finished five months later, 92.31% of the experimental group and 73.33% of the comparison group demonstrated formal reasoning skills on the Science Reasoning Task test (for more details please refer to Figures 2 and 3).

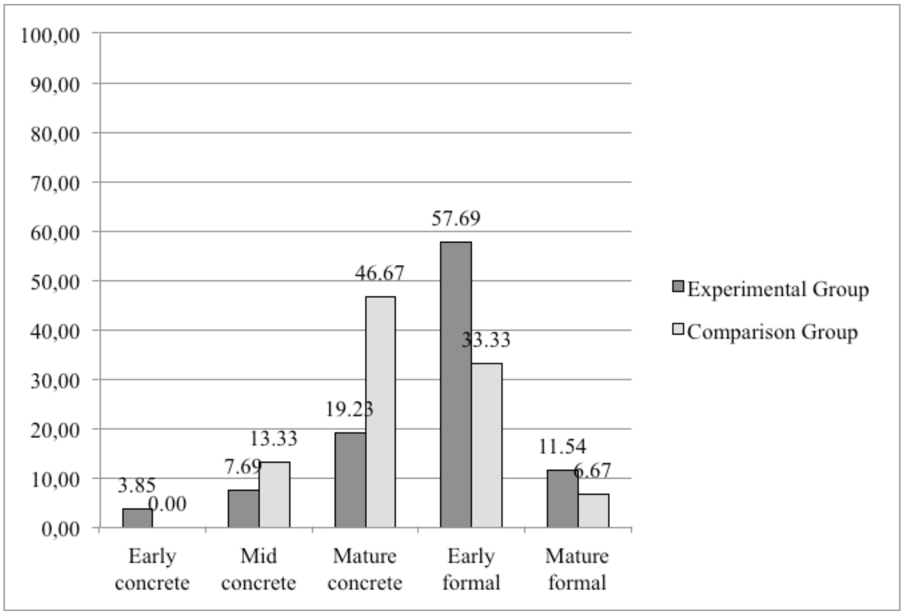


Figure 2. Experimental and comparison group reasoning level on the pre-test.

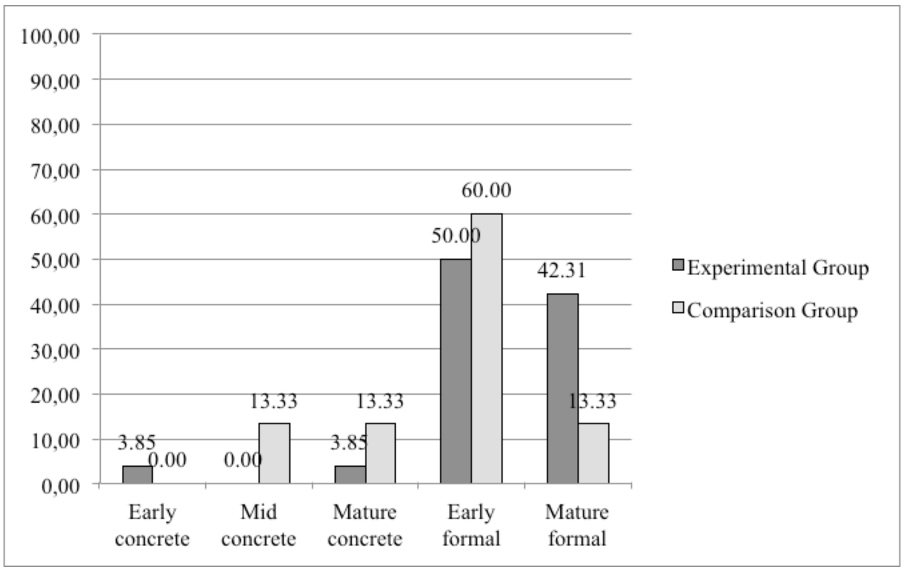


Figure 3. Experimental and comparison group reasoning level on the post-test.

Even though presenting the total percentages of prospective teachers who were able to think formally at the beginning and end of the CAME course is useful for understanding how many of them actually had the reasoning level they are expected to have, it does not show the whole picture of how many prospective teachers improved their reasoning level after the 5 months that the intervention lasted. For that reason, Table 8 presents information regarding the number of participants from the experimental and the comparison group, expressed in totals and percentages, that improved, maintained, or decreased their performance in the post-test in contrast with the pre-test.

Table 8
Changes in reasoning level of experimental and comparison group

| Performance from pre- to post-test | Reasoning level: Experimental group | | Comparison group | |
|---|---|---|---|---|
| | N | % | N | % |
| Improved | 16 | 61.54 | 8 | 53.33 |
| Maintained | 8 | 30.77 | 5 | 33.33 |
| Decreased | 2 | 7.69 | 2 | 13.33 |
| TOTAL | 26 | 100 | 15 | 100 |

It can be observed that a greater number of participants from the experimental group than from the comparison group improved their performance in the post-test in comparison with the pre-test. Even though the raw numbers shown in Table 8 might suggest that the CAME intervention was successful because a greater number of experimental participants improved their reasoning level, in order to draw a reliable conclusion it is necessary to further explore whether the difference is statistically significant. Thus, the next section will present the statistical tests that were conducted with the purpose of examining that difference.

## The impact of the CAME course on prospective teachers' formal reasoning skills

In order to compare the level of reasoning skills of the experimental and comparison group at the beginning and end of the CAME intervention, two Mann-Whitney U tests were run. The first test was intended to explore whether there was a difference between the experimental and the comparison group in terms of the participants' reasoning levels at the beginning of the intervention. Based on the mean ranks observed, it is possible to suggest that the experimental group showed higher reasoning levels (Mean Rank = 22.94) than the comparison group (Mean Rank = 17.63) at the beginning of the intervention (for more details, see Table 9). Even though there was an initial difference between the experimental and the comparison groups, the analysis suggested that the difference was not statistically significant ($U = 144.500$; $p > 0.05$).

Table 9
Pre- and post- Mann-Whitney U test ranks and statistics

| | Group | Mean rank | Sum of ranks | Mann-Whitney U | Asymp. Sig. (2-tailed) |
|---|---|---|---|---|---|
| Pre-test reasoning level | Comparison | 17.63 | 264.50 | 144.500 | .140 |
| | Experimental | 22.94 | 596.50 | | |
| Post-test reasoning level | Comparison | 16.17 | 242.50 | 122.500 | .030 |
| | Experimental | 23.79 | 618.50 | | |

As there was no statistically significant difference between the experimental and the comparison group in terms of their reasoning level at the beginning of the intervention, the next step was to run another Mann-Whitney U test in order to explore whether there was a difference between the groups at the end of the intervention. The analysis showed that the experimental group again had higher reasoning levels at the end of the CAME course (Mean Rank = 23.79) than the comparison group (Mean Rank = 16.17). However, this time the difference was statistically significant ($U = 122.500$; $p > 0.05$).

As has been observed in this section, the Mann-Whitney U test results suggested that the differences between the experimental and the comparison group, in terms of reasoning levels, might be explained by the participation of the experimental group in the CAME intervention.

## Discussion

### Implications for promoting formal reasoning skills in initial teacher training

The fact that only 58.53% of the sample demonstrated some ability to think formally at the beginning of the CAME course might suggest that the three initial teacher education programs that participated in this research are not sufficiently promoting the development of this kind of reasoning skills in their students. These results are consistent with previous research in the field (Barak & Dori, 2009; Leat, 1995; Lee, 2005; McDonald, 2010).

As described in the literature review section, the lack of formal reasoning skills observed in prospective teachers has led some scholars to stress the relevance of promoting thinking abilities during initial teacher education programs (Cox, 2007; Kennedy, 1990; McDiarmid, Ball, & Anderson, 1989; Reynolds, 1992) since they are essential not only for conducting good quality teaching practice, but also for improving these skills in their pupils.

In relation to this, Peterson and Treagust (1995) stated that teacher education programs should concentrate on the development of prospective teachers' pedagogical reasoning ability instead of overstressing the development of content knowledge. Only through this change of focus will teachers be equipped with the necessary understanding of the content, the curriculum, and the learners in order to make meaningful and effective decisions regarding their own teaching practice.

Based on the impact the CAME course had on participating prospective teachers' formal reasoning skills, it could be suggested that taking the cognitive acceleration approach is a viable strategy for improving initial teacher training courses in Chile in the future. In this regard, Fennema et al. (1996) agreed that promoting teachers' knowledge and understanding of their students' thinking is a feasible approach for changing and improving teachers' mathematical instruction, because they could use this kind of information to inform and to change their previous teaching practice.

### Implications for cognitive acceleration research: New horizons

Before the CAME course was actually delivered, it was impossible to be sure if the process of adaptation of the CAME activities was going to be successful in the sense of the lessons being adequate, motivating, and sufficiently challenging for working with prospective primary teachers in Chile. This uncertainty was partly because this was the first time that the CAME materials were being used with an older and different sample: prospective teachers, but also because the lessons were to be delivered in a completely different cultural context. Even though the adapted materials were well received and the early implementation during the pilot study provided significant feedback regarding ways of improving the final version of the materials, the uncertainty remained during the entire implementation process.

Despite all these reservations, the group of findings presented in the results section provided relevant evidence that supports the fact that using a Cognitive Acceleration approach with prospective teachers, can generate an impact on their ability to think formally. In this regard, CA programs have been suggested as a significant approach with students of different ages in a variety of school subjects and in different countries and cultural contexts. As a consequence, it is reasonable to claim that it is worth finding different and novel contexts, other than that of school students, in which this kind of initiative could be delivered and which might contribute to the development of thinking skills that are needed so desperately in this globalized information era.

## Limitations

### The limits of CAME's explanatory power: Time and other training instances

In order to analyze the scope of CAME in accounting for the improvements observed in the participants, it is important to bear in mind that, when an intervention is trying to promote a certain kind of cognitive development, as in the case of CAME, that development is necessarily influenced by the natural maturation process that occurs in every person over time. In other words, it is almost impossible to establish a dividing line between the changes that are explained by the direct or indirect effect of the CAME intervention, and the magnitude of the change that is attributable to the time that has passed.

In this context, the time (five months) that elapsed between the beginning and end of the CAME course is one of the variables that could interfere with its explanatory potential. However, every intervention study has this limitation and, therefore, this research used a control group in order to be rigorous in terms of controlling the effect of time. In this sense, not finding the same improvements in the control group in comparison with the experimental might be considered a sufficiently strong argument in favour of the impact of CAME lessons.

In addition to the time, the fact that prospective teachers were participating in other university courses that were part of their Bachelor of Education programs is another limitation for the explanatory potential of CAME. In this regard, prospective teachers were engaged in other courses related to mathematics and to teaching primary children as part of their training to qualify as primary teachers.

As a result, it is impossible to be sure that the changes observed in the experimental group were the sole result of the intervention. Again, in these kinds of cases, the main tool that provides insight into the effectiveness of the intervention is having a control group that allows comparison of the experimental participants with similar students (control participants) under similar conditions. Therefore, the fact that the control group did not improve their formal reasoning skills to a similar extent as the experimental group over the same period of time is still an argument that backs up the effect of the CAME course.

### Limitations associated with the administration of the science reasoning task

To compare the performance of the experimental and the comparison group at the beginning and end of the intervention, Task II from the Science Reasoning Task test was used (Shayer, 1977). Even though is a relatively short test that can usually be answered in 30-40 minutes on average, it was possible to observe that the comparison group showed low levels of motivation when taking the test. In contrast, the experimental group considered the SRT test to be part of the “duties” they needed to carry out to participate in the CAME course. In fact, most control participants devoted little time to answering each question, with the purpose of leaving the room as soon as possible. This phenomenon may partly explain the lower results obtained by the control group in the SRT, a hypothesis that is not easy to discard considering the small sample size. In this context, further research is needed in order to add understanding to the conclusions reached by this particular study. The next section will take the discussion of the sample size further.

### Limitations related to the sample size

The small sample size was problematic, particularly for drawing statistical inferences from the SRT test results. Even though the study intended to recruit a larger sample from each participating university, it was extremely difficult to recruit voluntary students because participation in the study was very time-consuming. In other words, in the case of the experimental participants, being part of the research project involved coming to a CAME session every week for the entire university semester and also involved taking a test at the beginning and end of the course. Even though all the participants were free to leave the course at any time during the semester, the conditions of participation implied a high-level and long-term commitment right from the start. This could be one of the main reasons that may explain the difficulty in recruiting a larger sample.

The control group was also difficult to recruit, particularly because their participation was limited to taking a test at the beginning and end of the semester. While the experimental group experienced certain benefits as a result of their association with the CAME course, the control group did not perceive any benefits in taking the test so, even when a higher number of students agreed to take the test at the beginning of the semester, it was extremely difficult to persuade them to return a second time at the end of the course. As a result, it was impossible to consider the sample from each university separately and to run comparisons between groups. In contrast, the only choice was to consider all the experimental and comparison students as just two groups, even though the students within each university were, in fact, quite dissimilar.

## Future research

Cognitive Acceleration programs have been implemented since the 1980s and have subsequently produced promising results in terms of students' cognitive gains and academic achievements (Adey & Shayer, 1990; Demetriou, Platsidou, Efklides, Metallidou, & Shayer, 1991). For this reason, even when the first CA program was delivered within the context of science, CA interventions began to be developed in other school subjects (Adhami et al., 1998; Adhami et al., 2005; Shayer & Adhami, 2003), with students of different ages (Adey, Robertson, & Venville, 2001, 2002; Adhami et al., 2005; Shayer & Adhami, 2003), and in various countries (Endler & Bond, 2008; Iqbal & Shayer, 2000; Mbano, 2003).

As a result, CA became not only a successful intervention for promoting students' formal reasoning skills, but also a highly structured approach to teaching and learning that was frequently associated with rigorous follow-up and research processes. This is one of the salient characteristics of CA research because, within the educational field, there are many teaching/learning models that are successful within the classroom but which do not transcend those limits because nobody knows about them. In contrast, the case of CA is very informative because most of the new initiatives have been closely linked to research and, as a result, their impacts have been rigorously documented.

In this context, it is somewhat difficult to state that trying out a CA approach with prospective teachers adds completely new evidence to the existing body of knowledge, or that there are still many unexplored lines of research, because CA research has been active for more than 30 years. However, it is possible to suggest that this study has added some useful insights to the corpus of CA research and that there may be some interesting approaches that could still be developed.

As described in a previous section, every CA program has two lines of action. The first involves the application of the CA activities instead of regular lessons once every two weeks, with the purpose of promoting students' thinking skills. The second, which is equally important, is the implementation of a professional development (PD) program for teachers in order to enhance their understanding regarding the theory and the principles behind the CA approach and to promote the skills they need in order to implement the program with their students.

In comparison with the huge amount of CA research that has attempted to measure the impact that CA acceleration programs have had on students' thinking skills and academic performance in other subject areas (i.e. Adey, 2005; Adhami et al., 1997; Cattle & Howie, 2007; Endler & Bond, 2008; Mbano, 2003; Shayer & Adhami, 2007; Shayer et al., 1999), little research has been primarily interested in exploring the impact that the PD program has had on the teachers participating in it (Adey, 2004; Hodgen, 2003; Johnson, Hodgen, & Adhami, 2004).

Based on the evidence that CA research has produced and the findings of this research, it is reasonable to think that pre-service teachers might have experienced significant changes in terms of their views and approaches to teaching and learning mathematics after participating in the program, as the in-service teachers have done (Hodgen, 2003; Hodgen & Askew, 2007; Hodgen, Johnson, & Adhami, 2004; Johnson et al., 2004). In other words, the success of the PD program relies not only on in-service teachers becoming capable of delivering the CA program effectively, but also on them moving towards more productive approaches to teaching and learning. In this sense, even though this study did not look at any of those other changes, it would be interesting to include them in future research.

Finally, another aspect that would be worth exploring is to keep developing these kind of initiatives in other cultural contexts, in order to find out if it is possible to claim that the CA approach is universally successful and is not dependent on the country in which it is applied. In addition, it would also be interesting to replicate the experience with other groups of prospective teachers from other countries since this research was the first experience with these students.

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