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Mathematical Problem-Solving Abilities and Chess: An Experimental Study on Young Pupils

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Abstract

Chess is thought to be a game demanding high cognitive abilities to be played well. Although many studies proved the link between mastery in chess and high degree of intelligence, just few studies proved that chess practice can enhance cognitive abilities. Starting from these considerations, the main purpose of the present research was to investigate the potential benefits of in-presence chess lessons and on-line training on mathematical problem-solving ability in young pupils (8 to 11 years old). Five hundred sixty students were divided into two groups, experimental (which had chess course and on-line training) and control (which had normal school activities), and tested on their mathematical and chess abilities. Results show a strong correlation between chess and math scores, and a higher improvement in math in the experimental group compared with the control group. These results foster the hypothesis that even a short-time practice of chess in children can be a useful tool to enhance their mathematical abilities.

Keywords

education, social sciences, achievement, science, math, and technology, curriculum, educational research, education theory and practice, educational psychology, applied psychology, psychology, cognitivism, approaches, experimental psychology

Introduction

Many studies have analyzed the relationship between general intelligence and chess abilities. In particular, some of them have investigated the correlation between these two variables suggesting that the chess players' population (both adults and children) is more intelligent than the general one (Doll & Mayr, 1987; Frydman & Lynn, 1992; Horgan & Morgan, 1990). This evidence, however, does not necessarily lead to the conclusion that chess improves intelligence because the direction of the causality is uncertain (Gobet & Campitelli, 2002). In fact, there are several possible alternative explanations for that: A high IQ could be the cause of a high chess ability (and not vice versa); in other words, an intelligent individual achieves a high chess ability just because chess requires a high degree of intelligence, but it does not increase it; or, alternatively, high-IQ people could be "selected by the game" much more easily than others: Subjects playing chess can find out that they are good at the game, so they are encouraged to continue to play it. However, whoever turns out to be not so good at chess can be discouraged to play it again. In this case, chess "selects" motivated people with a high IQ who are able to play well (Gobet & Campitelli, 2006).

Beyond the question of direction of causality, the more general problem of the transfer of skills must be held in consideration. If the former problem is addressable by using a proper experimental design (experimental and control groups; pre- and post-tests), the latter represents a theoretical problem since the seminal work of Thorndike and Woodworth (1901). Their theory of *identical elements* states that the transfer of cognitive abilities, from a domain to another one, occurs only when the domains share common elements. This implies that the transfer of skills is quite rare and limited to the extent that there is an overlap between the domains (Anderson, 1990; Singley & Anderson, 1989; Travers, 1978).

Some studies have shown that this applies to the game of chess too. In her classical study, Chi (1978) demonstrated that chess players' memory skill for chess positions did not extend to digits recall. Schneider, Gruber, Gold, and Opwis (1993) replicated the study and obtained the same outcomes. More recently, Unterrainer, Kaller, Leonhart, and Rahm have found that chess players' planning abilities did not transfer to the Tower of London, a test assessing executive function and

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planning skills (Unterrainer et al., 2011); in Waters, Gobet, and Leyden (2002), chess players' perceptual skills did not transfer to visual memory of shapes; and finally, chess abilities did not correlate with performance in a beauty contest experiment (Bühren & Frank, 2010). All these studies have suggested that transfer is, at best, improbable, and that chess players' special abilities are context-dependent.

Given that the more specific a skill is, the less that skill is transferable to another domain; nevertheless, it is reasonable to suppose that a game requiring attention, logical thinking, planning, and calculation abilities would be able to improve at least some of the aforementioned abilities, which are linked to the problem-solving competence and, overall, to general intelligence, at the beginning of their development. Put simply, if chess players' abilities do not transfer to other domains, it is not impossible that chess helps children developing the above abilities, especially when these latter are yet to be fully developed, and still general enough to allow the transfer.

This hypothesis is supported by those studies investigating the effect of the chess courses on children's mathematical abilities (Barrett & Fish, 2011; Hong & Bart, 2007; Kazemi, Yektayar, & Abad, 2012; Scholz et al., 2008; Trinchero, 2012a). Such studies have found that children attending chess lessons show significant improvements in mathematical abilities. This is even true for low-IQ subjects: Scholz et al. (2008) found that children with an IQ ranging from 70 and 85, attending 1 hr per week of chess lesson instead of 1 hr of mathematics, performed significantly better in addition and counting than children who did not receive chess lessons; Hong and Bart (2007) found a correlation between chess ability and non-verbal intelligence in students at risk of academic failure, suggesting that chess ability can be a predictor of improvement in cognitive abilities; Barrett and Fish (2011) tested 31 students, receiving special education services, divided in 2 groups: One had chess lesson once a week instead of a lesson of mathematics, whereas the other one had two lessons per week of mathematics, but no chess lesson. This study showed that the chess group improvements in "number, operations and quantitative reasoning" and in "probability and statistics" were significantly higher than those obtained by the other group who did not attend any chess activity. Similar results have also been found in pupils with normal IQ and without specific disabilities (Kazemi et al., 2012; Liptrap, 1998; Trinchero, 2012a, 2012b). In all these studies, positive effects of chess appeared after at least 25/30-hr courses. Studies of Trinchero (2012b) and Kazemi et al. (2012), which investigated the effects of a chess course on children's (third graders in Trinchero, 2012b, fifth, eighth, ninth graders in Kazemi et al.) mathematical problem-solving ability, deserve a particular attention. Both of these studies have found a significant improvement in problem-solving scores in chess-trained children compared with children who have not performed any chess-related activity. These results suggest that chess could increase not only basic mathematical abilities (as calculation or addition) but also competences, such as mathematical problem-solving abilities. Starting from these data, the aim of the present study was to verify whether a blended strategy (Trinchero, 2013) consisting in a 10- to 15-hr chess course supported by a computer-assisted training (CAT) is able to improve mathematical problem-solving ability in children in a shorter time compared with other previous studies. Assuming that at least some chess abilities can be transferred from chess to the mathematical problem-solving domain, our hypothesis is that the chess-trained children group will show a significantly higher improvement in mathematical problem-solving skills compared with children who did not receive any chess training, and among the subjects who received chess training, those who used the CAT more will show a higher improvement.

Material and Method

Participants

The study was conducted on a total of 31 classes (third, fourth, and fifth grades) from 8 different schools of Northern Italy. The classes were randomly assigned to two groups, including 17 classes in the experimental group and 14 in the control group.

The experimental group included 5 fifth-grade classes, 10 fourth-grade classes, and 2 third-grade classes for a total of 309 students (169 males and 140 females). One hundred ninety-three children included in this group declared to be able to play chess before the beginning of the study. The control group included 6 fifth-grade classes, 3 fourth-grade classes, and 5 third-grade classes for a total of 251 participants (116 males and 135 females). Seventy-two children in this group declared to be able to play chess before the study.

Study Design

Students in the experimental group received a mandatory chess course based on the SAM (Scacchi e Apprendimento della Matematica; Chess and Maths Learning) protocol (design by the Italian Chess Federation instructors Alessandro Dominici, Giuliano d'Eredità, Marcello Perrone, Alexander Wild; for further information, see www.europechesspromotion.org). In addition, each pupil in the experimental group was provided with a free software, named CAT (see Trinchero, 2012a, for further details), for learning the game of chess every time he or she wanted. The use of CAT was not mandatory, yet highly recommended. The pupils of the experimental group were given the opportunity to play CAT at home. Two variables were recorded by CAT: time of utilization and level achieved.

On the contrary, students in the control group performed only the normal school activities without any chess-related activity. The chess courses lasted between 10 and 15 hr (1 or 2 hr per week, according to the schedule and the availability

Table 1. The Seven Mathematical Problem-Solving Items of the Seven OECD-PISA Items.

Math abilities involved	Estimated difficulty (from OECD-PISA)	Score	Analogy with chess ability
Calculate the number of points on the opposite face of showed dice	478 (Level 2)	0/1	Calculate material advantage
Extrapolate a rule from given patterns and complete the sequence	484 (Level 3)	0/1	Extrapolate checkmate rule from chess situation
Calculate the number of possible combination for pizza ingredients	559 (Level 4)	0/1	Explore the possible combination of moves to checkmate
Calculate the minimum price of the self-assembled skate-board	496 (Level 3)	0/1	Calculate material advantage
Recognize the shape of the track on the basis of the speed graph of a racing car	655 (Level 5)	0/1	Infer fact from a rule (e.g., possible moves to checkmate)
Establish the profundity of a lake integrating the information derived from the text and from the graphics	478 (Level 2)	0/1	Find relevant information on a chessboard
Estimate the perimeter of fence shapes, finding analogies in geometric figures	687 (Level 6)	0/1	Find analogies in chessboard situations

Note. OECD-PISA = Organisation for Economic Co-Operation and Development–Programme for International Student Assessment.

of the schools involved), and were conducted by three Italian Chess Federation teachers. The teaching program and the methodology were exactly the same for each course. Courses were aimed at teaching the basic rules and tactics of the game (material value, checkmate patterns, basic endgames).

All students (both in the experimental and in the control groups) were tested before and after the intervention using the seven Organisation for Economic Co-Operation and Development–Programme for International Student Assessment (OECD-PISA) items (Organisation for Economic Co-Operation and Development, 2009), a validated instrument to assess mathematical problem-solving abilities with several degrees of difficulty (see Table 1), and a 12-items questionnaire to assess chess abilities (Trinchero, 2013; see Table 2). Time between the pre- and post-test evaluation was 3 months.

The design of the study is summarized in Table 3.

The main limitation is the lack of a placebo group, that is, a group whose participants undergo alternative intervention. The two-groups design does not allow to understand whether the potential improvement in math performance was due to chess-specific or chess-unspecific factors. It is possible that other non-specific ludic activities, demanding attention and slow thinking, can increase mathematical problem-solving abilities as well. The second limitation is that the number of pupils declaring to be able to play chess is significantly greater in the experimental group than the control one. It is advisable, for future studies, to select participants from not-chess-players samples, or to match the numbers of players between groups to better control this variable. The third limitation is that chess lessons were administered by three different instructors. This was necessary for organizational needs, but we tried to control it asking the three instructors to follow the same didactic protocol throughout all the chess courses.

Table 2. The Twelve Chess Items Used to Evaluate Chess Knowledge.

Chess ability	Score
Explain checkmate situation	0/1
Identify checkmate situation	−3/+2
Establish if a move is allowed for a piece	−2/+2
Identify castling situation	0/1
Calculate material advantage	0/1
Identify common elements in three chess situations	−3/+3
Identify pawn promotion	0/1
Identify the possibility of insufficient material	0/1
Identify checkmate situation	0/1
Identify checkmate-in-one-turn situation	0/1
Reconstruct sequence of chessboard events	0/1
Identify common elements in three chess situations	−3/+3

Finally, the classes were randomly assigned to the two groups, but the single student were not (that is, every student remained in his/her regular school class). Nevertheless, it must be noticed that organizing a well-designed experimental research in educative contexts is difficult, and randomizing students without their classes is often a non-acceptable practice in schools due to organizational reasons.

Results

Data were analyzed using a series of t tests, mixed linear models, and correlation analyses.

The two groups were equal in terms of mean age: M(e) = 8.99 years (SD = 0.90 years), M(c) = 9.05 (SD = 1.12 years), $t(558) = -0.76$, p = .45, and pre-intervention mathematical

Table 3. Description of the Experimental Design.

Groups	*n*	Activities		
Experimental	309	Pre-test *T*(0)	Blended chess training (10/15 hr of chess course and non-mandatory CAT activities; 3 months)	Post-test *T*(1)
Control	251	Pre-test *T*(0)	Regular school activities (not chess-related activities; 3 months)	Post-test *T*(1)

Note. CAT = computer-assisted training.

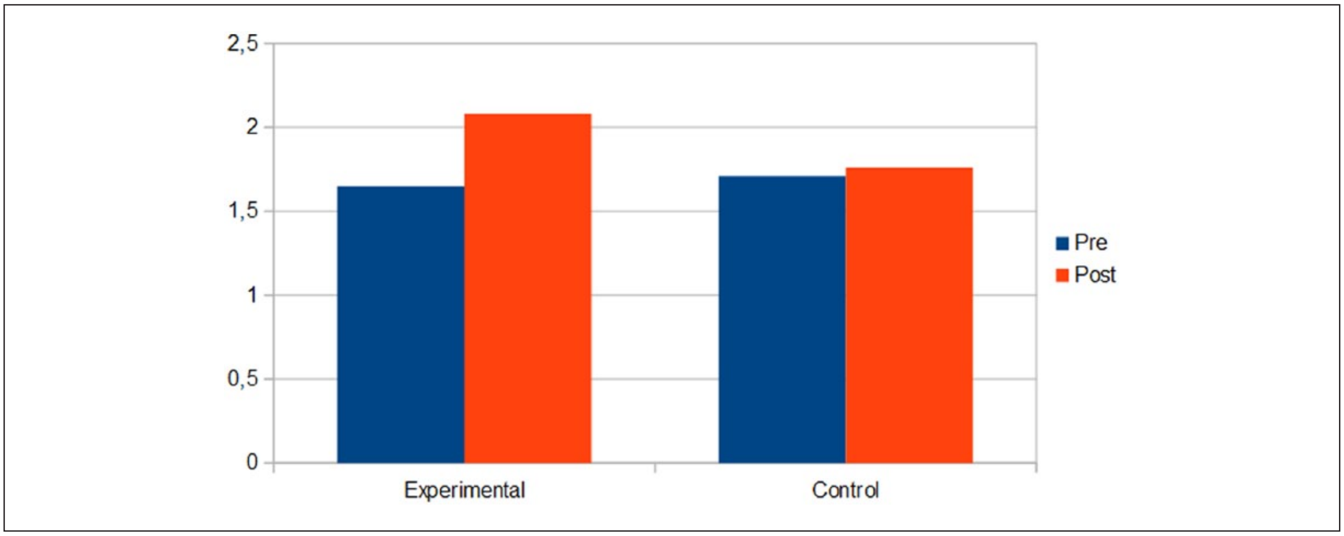

Figure 1. Math scores in the two groups of pupils measured before and after the intervention.
Note. The experimental group performance in the post-test was significantly higher than in the pre-test, whereas the control group did not show any improvement.

problem-solving scores, *M*(e) = 1.65, *SD* = 1.15; *M*(c) = 1.71, *SD* = 1.12, *t*(558) = −0.60, *p* = .55. Post-intervention mathematical problem-solving scores were *M*(e) = 2.08, *SD* = 1.34; *M*(c) = 1.76, *SD* = 1.24.

Because the participants were from eight different schools, a mixed linear model was performed, to rule out the potential role of school of provenance (as participant variable) in determining math post-test results (dependent variable). The model showed a significant effect of group, fixed factor, *F*(1, 45.670) = 7.179, *p* = .01; and a significant effect of math pre-test scores, fixed covariate, *F*(1, 550.297) = 109.080, *p* < .001; but no significant effect of age, fixed covariate, *F*(1, 184.246) = 2.809, *p* = .10; and no significant effect of school of provenance, var(u_{0j}) = 0.035, *p* = .32, either. Figure 1 summarizes math pre- and post-intervention scores in the two groups.

Regarding the chess performance, pre-intervention chess scores were significantly higher in the experimental group than in the control group, *M*(e) = 3.34, *SD* = 4.08; *M*(c) = 1.34, *SD* = 2.99; *t*(558) = 6.49, *d* = 0.56, *p* < .001. A mixed linear model was performed, to rule out the potential role of school of provenance (as participant variable) in determining chess post-test results (dependent variable). The model showed a significant effect of group (fixed factor), *F*(1, 125.917) = 309.433, *p* < .001, and a significant effect of chess pre-test scores (fixed covariate), *F*(1, 507.482) = 251.567, *p* < .001; but no significant effect of age (fixed covariate), *F*(1, 342.990) = 0.306, *p* = .58, and no significant effect of school of provenance, var(u_{0j}) = 0.523, *p* = .17, either. Figure 2 summarizes chess pre- and post-intervention scores in the two groups.

Post-intervention chess scores and math performance in the experimental group were significantly correlated (*r* = .29; *p* < .001; *N* = 309).

Experimental group participants' use of CAT was quite heterogeneous: *M* = 3.24 hr (*SD* = 4.29), *M* = 6.00 levels achieved (*SD* = 4.94). Post-intervention math scores and the CAT level achieved by students in the experimental group were significantly correlated too (r_s = .22; *p* < .001; *N* = 309); however, post-intervention math scores and CAT time of use were not correlated (*p* = .29).

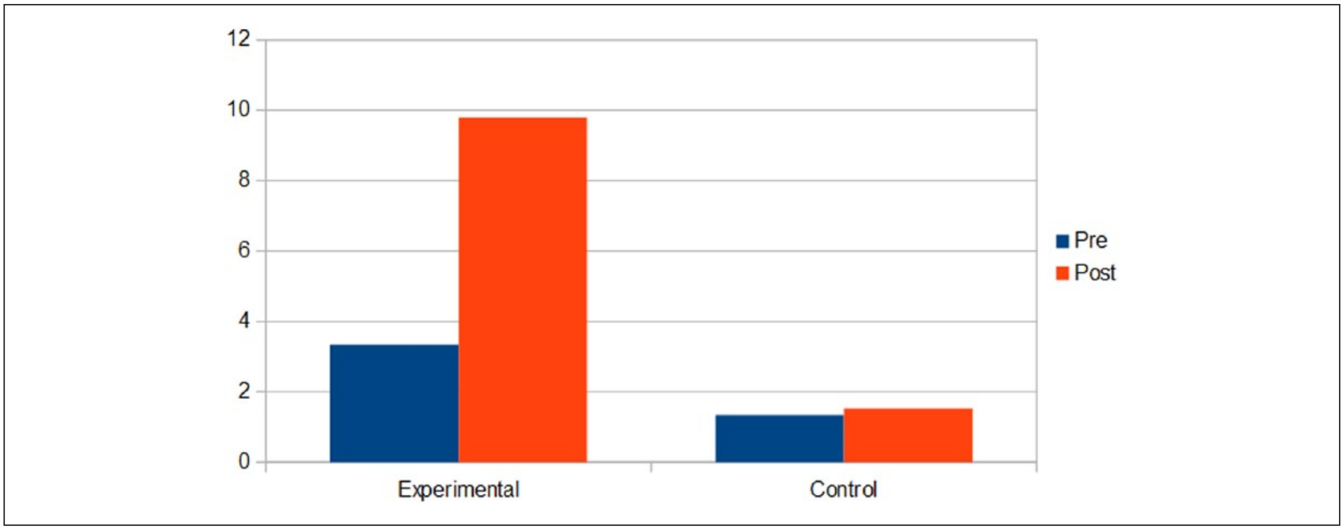

Figure 2. Results of the two groups in chess ability.
Note. Only the experimental group improvement was statistically significant.

Discussion

The hypothesis of the study, according to which the mathematical problem-solving scores gain in the experimental group would be significantly higher than the one in the control group, is confirmed. Moreover, we found that both the chess scores and the CAT level achieved by the students in the experimental group were significantly correlated with the mathematical problem-solving scores. Because part of protocol was not mandatory, that is, CAT activities at home, it is possible that those who played CAT more (in terms of time) were more motivated by chess, and hence the better mathematical scores. However, only the level achieved by the pupils proved to be correlated to math post-test scores, whereas time of utilization did not. If we assume that the time spent playing CAT was, to a certain extent, a measure of the participants' motivation toward chess, then this seems to suggest that motivation was not a crucial factor of math results. On the contrary, chess ability, assessed by chess score and CAT level achieved, proved to be more reliable at predicting math scores. In summary, these results show that a blended strategy of intervention (in-presence chess lessons followed by home training) can be effective both to teach chess and to enhance mathematical abilities. These outcomes are impressive considering that, compared with the previous studies based on 25/30 hr of chess lessons, our intervention consisted only in 10/15 hr of in-presence chess teaching activities.

Given these results, how can the education and practice of chess affect the logical–mathematical abilities of the young pupils? To answer this question, we can hypothesize that the intrinsic feature of the game can be the cause of the phenomenon to be explained. Chess is based on some mathematical elements as the values and the geometrical movements of the pieces. According to Scholz et al. (2008), the practice of the game can convey some notions of the mathematical domain as the concept of numerosity. Throughout a chess game, a chess player is requested to pay attention to the material advantage (or disadvantage) because, together with the two Kings safety, it is the most important aspect of the game. Material advantages are calculated by summarizing all the white and black pieces' values (every piece has a specific value, depending on how it moves); the comparison between these two sums gives the players the basic criterion for the evaluation of the chess position:

> *This conception fits well in the context of positive conditions for transfer* ["*Low road transfer happens when stimulus conditions in the transfer context are sufficiently similar to those in a prior context of learning to trigger well-developed semi-automatic responses*." (Scholz et al., 2008, p. 139)] *described by Perkins and Salomon* (Perkins & Salomon, 1994), *since the strength of the chess pieces can be used as a metaphor for numbers*. (Scholz et al., 2008, p. 146; emphasis added)

In other words, chess could have the power to "materialize" some mathematical abstract concepts so that children can learn and manage them much more easily. In Kazemi et al. (2012), a similar explanation is given:

> When students experience the subtlety and sophistication of chess play, upon encountering complex and subtle matters, they often associate or link these two elements and discover the logic and subtlety of mathematics. In reality, this complexity may take tangible or real forms for students (p. 378).

This is also consistent with the concept of embodiment of mathematical elements described in Lakoff and Núñez (2000).

Furthermore, chess, by its nature, is a game that forces players to use skills that go beyond the simple calculation of variations, or mere mnemonic exercises: Playing chess is an exercise of competence. A chess player must monitor his own strategies and, therefore, his own thoughts, focus on detail, and use abstraction and generalization, even at amateur level. The positions appearing on the chessboard during the game are problems to be solved by choosing a move or a combination of moves. In addition, the absence of the aleatory element forcefully leads players to attribute the cause of their success (or failure) to the quantity and quality of their effort and their own strategic choices, promoting the empowerment process. In other words, a chess player becomes aware of his own self-effectiveness. According to Trinchero, children's attentive skills could be enhanced by the practice of the game of chess, and this fact could explain the improvements in mathematical problem-solving abilities related to game practice: "this difference may be due to the increased capacity of the pupils of reading and interpret correctly the mathematic problems, apply their mathematic knowledge and reflect on their own actions and strategies, as effect of chess training" (Trinchero, 2013).

We can summarize the above concepts by saying that chess increases mathematical problem-solving skills because (a) math and chess are isomorphic domains; by playing chess, math concepts are made less abstract and thus more manageable; (b) a chess player must use high skills as planning, abstract thought, calculation of variants, monitoring of strategies, and thoughts that are necessary in mathematical skills; (c) a chess player perceives the victories and defeats as a result of his choices on the board, the correctness of which is proportional to the practice and the efforts of the player himself; this is supposed to increase the empowerment of the player and, consequently, the confidence in his own abilities; (d) the chess player becomes aware of the necessity of enduring attention, addressed to both the simple elements of the game and to the dialectical relationship between elements; attention that is already potentially present in the participant, but that the actual environment and habits tend to reduce; (e) chess is an amusing and rewarding activity that encourages children to play more. In other words, chess gets a "virtuous circle" started, and this circle can be very useful also to develop good mathematical abilities.

This explanation is realistic because it can be compatible with two opposite paradigms about the conditions under which cognitive transfer happens and, in a vaster perspective, about the features of human intelligence. Logical skills (and intelligence) can be considered context-dependent or context-independent. In the first case, the problem-solving ability is strictly linked to the domain of application; thus, a participant can show problem-solving skills as good in a field of knowledge and as bad in another one. In the second case, logical skills are universal and disconnected from the context of application. According to the latter perspective, the human intelligence is the sum of several basic abilities through which higher competences, such as problem-solving, arise. The issue is still debated.

As we previously said, the assumption subtending our hypothesis is that some abilities can be transferred from chess to the mathematical domain. Transfer can occur when there is a certain degree of overlap between the two domains, and the extent of the transfer itself is limited to that degree (Thorndike & Woodworth, 1901). Thus, the more specific knowledge becomes, the more difficult transfer of skills can arise (Ericsson & Charness, 1994), and the ability in a certain task depends on the context of application. In these terms, it is unlikely that chess can be useful to teach mathematics.

Nevertheless, several authors think that the transfer is possible because of the general nature of the cognitive processes: a fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Sternberg, 2008) that can be trained. If chess training can boost some basic abilities easily generalizable to mathematics domain (because of the similarity between the two domains), then it is possible that chess improves a higher competence such as mathematical problem solving. In other words, the problem of the transfer is played on a trade-off between generality skill and a sufficient isomorphism (Atherton, 2007) between the nature of the domain in which the pupil exercises the skill and the new domain into which the skill can be transferred; a trade-off between universality and specificity (Sala, 2013). Thus, the two perspectives should not be considered irreconcilable. The question is, in what ratio is a certain competence based itself on general cognitive abilities and in what ratio on a domain of application? Regarding chess, the data, currently, do not allow to infer the answer.

It is possible to suppose that chess is a sort of medium through which some cognitive abilities are boosted. A theoretical framework for this hypothesis could be the conception of intelligence described by Feuerstein, Feuerstein, Falik, and Rand (2006). According to this perspective, intelligence is a repertoire of universal cognitive functions, able to operate on every content. Some of these functions such as the "precision and accuracy in the data collection," the "ability to understand the existence of a problem," the "ability to distinguish relevant from non-relevant data," the "need of logical proves," and the "planning behavior" are necessarily needed during a chess game. For example, a chess player searching for a checkmate combination has to realize that the position on the chessboard offers that opportunity, has to collect the data very carefully (a single piece or square not considered and the combination could fail), has to select the relevant data (not necessarily all the pieces are involved), has to plan the combination considering the foe's defense chances, and needs to prove the cogency of his inference. All these functions contribute to solving the chess problem and, in a more general sense, are undoubtedly involved in every field of problem-solving application.

If the assumption of a repertoire of universal cognitive functions, context-independent and thus applicable to several domains, is accepted, then it is necessary to ask for the reason why chess is one of the ideal mediums. The aforementioned features of the game (aleatory component null, need of heuristic thought, similarities with mathematics domain) are essential, but it must be considered that chess is a content itself. According to Feuerstein et al. (2006), a cognitive function has to be trained with a specific content, selected for its intrinsic features. The content must not be so unfamiliar to invest a great effort that would take precious cognitive resources and would not allow the pupil to concentrate on the function to strengthen. However, the content must not be too familiar either, because it would not be able to induce a state of attention in the pupil; so he would not mobilize his cognitive resources because of the lack of intrinsic motivation. Chess could be an ideal medium because it is familiar enough: It is a board game, quite known, and based on quantity, calculation, and planning, which are concepts already experienced by children in school; however, chess is a game compelling and new for most of the children involved in a chess course, so it is simple to induce passion for it.

Furthermore, it is important to underline not only the intrinsic features of the game of chess but also the method through which chess is taught. If it is assumed that a chess course is a tool to boost problem solving or similar abilities, then a chess teacher is supposed to propose activities selected on purpose. In this sense, it is important to note that, although in the present study, the number of pupils declaring to be able to play chess in the pre-test is higher in the experimental group (193) than in the control group (72), and, consequently, chess scores are higher in the experimental group pre-test, the mathematical problem-solving scores of the experimental group are not significantly different. This fact can be explained by saying that the mere knowledge of chess basic rules (as the movement of the pieces) is by far insufficient to train cognitive skill. It is hard to see why knowing that the Rook can move vertically and horizontally, for example, should improve children problem-solving skills, or any other intellectual skill. On the contrary, knowing how to find the shortest path from one square to another one for the Rook, or knowing whether it is worth to give up a Rock for a Queen, is a more demanding task for the intellectual skills of the pupil. A pupil playing a chess game moving the pieces correctly (that is, according to the rules), but without any plan or calculation, does not use any problem-solving ability.

On the contrary, it is reasonable to assume that a pupil playing a chess game moving the pieces according to a strategy (albeit ingenuous or shallow for an expert chess player) and paying attention to the dynamic relationships between the pieces is training his or her problem-solving ability.

Further studies are needed also to deepen our knowledge about the effect of chess training on cognitive abilities. We can consider three main lines of research: (a) the study of the cognitive processes subtending the outer phenomenon, that is, the amelioration in mathematical problem-solving competence; (b) the long-term effects of chess training on mathematical abilities; and (c) the comparison between chess and other mathematical games.

The first line refers to the already discussed issues: If it is possible to state that a chess course, with a proper didactic program and methodology, improves children mathematical problem-solving abilities, it is not yet possible to say exactly why this happens. Which are the cognitive skills strengthened by chess? Just a few experimental studies directly assessed the increments of some cognitive abilities after a chess intervention. In the study of Scholz et al. (2008), the experimental group did not improve in the concentration abilities, suggesting that the amelioration of the experimental group calculation scores was not due to the increase of the concentration of the participants. However, it must be considered that the participants of that study were children with IQ (70-85) lower than the average of the population, so that sample could not be representative for the general population. In the study of Kazemi et al. (2012), the participants were tested, after a 6-month chess course, to assess their meta-cognitive abilities, along with their problem-solving skills: The researchers found a significant advantage for the experimental group (who received the chess course) both in the meta-cognition scores and in problem-solving scores. This fact leads to think that the meta-cognitive abilities boosted by chess practice can be successfully transferred into mathematics domain.

The second line of research, suggested by Gobet and Campitelli (2006), is necessary to assess the endurance of chess training benefits during the 2 or 3 years. To date, follow-up data related to chess and its educational benefits do not exist. If these benefits disappeared, for example, 1 year after the intervention, then chess would not be an educational useful tool. If the transfer is possible only when there is an overlap between the two domains, then an activity getting more and more specific, at a certain point, becomes ineffective, because it insists on capacities not shared by the two domains, and thus not transferable. So, it is likely that the benefits of the chess training diminish with the second or the third year of training (following a sort of logarithmic curve) because of the increasing specificity of the topics. In other words, it would be important to know when the costs of a chess course overcome the benefits.

The third line of research could be useful to understand whether other mathematical games can be used as educational tools, and to understand which mathematical skills are enhanced by chess and by other games. Ferreira, Palhares, and Silva (2012) tested the correlation between the skills of children in some games (such as Dots and Boxes, Wari and Traffic Lights) and several mathematical factors (such as numeric and geometric progression, counting, rotation) finding that every game has specific correlation with one precise factor. The study, although interesting, is correlational, so it is impossible to infer that those games can boost some mathematical abilities. Gobet (personal communication) suggests that some aspects of the school curriculum might be better illustrated by other games, such as Awele, Go, and Bridge. Not enough has been done to infer anything certain.

In conclusion, although many aspects of the potential benefits of chess practice in children are still unknown, we can state that the game of chess is a powerful tool to build children's problem-solving competence in the mathematical domain, even with brief courses, such the one we propose to our pupils.

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