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Research paper

Impact of a neuroscience intervention (NeuroStratE) on the school performance of high school students: Academic achievement, self-knowledge and autonomy through a metacognitive approach

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A R T I C L E I N F O

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A B S T R A C T

Background: Contributions from the cognitive neurosciences encourage the development of innovative tools in learning. Through an innovative intervention program called NeuroStratE, we conducted a study to analyze the impact of brain knowledge, with metacognitive approach, on the academic performance of students. This analysis concerns a cohort of 311 students aged 16. Students' school results were collected over one year and compared with those of a control group. These results are qualitatively refined with student feedback on the value of the intervention program, along with individual teacher interviews. This study showed no significant difference in school results between the two groups of students. However, the study shows the relevance of the program and students acquired knowledge about the brain's functioning. Moreover, this intervention highlights the evidence of the emergence in students of greater autonomy and better self-knowledge, both contributing to a feeling of self-efficacy, which is at the core of educational success.

1. Introduction

There have been important advances in neuroscience, concerning education, over a number of years [1]. With heightened scientific knowledge of cerebral activity in the course of learning, comes the possibility for educators to use interesting tools to improve school performance [2–5]. They see opportunities to use this increased knowledge in the school domain, particularly in the classroom. Based on the research on brain function, educators have constructed tools that have been shown to be beneficial to learning. While these tools constitute an important and critical element to the learning process, in the current study the emphasis is placed differently; that is, to teach students to become familiar with the functioning of their own brains and then to mobilize their metacognitive resources.

This latter approach appears to have a much greater impact, particularly in school results [6]. Our study thus concerns the effects of pedagogical elements on knowledge of one's brain and its functioning, and the application of these elements on students aged 16 years, entering the high school (i.e: the Lycée) in the French education system. Thus, a metacognitive approach may have a positive effect on school results and more generally on overall school success, particularly since this approach may favor better self-knowledge and the development of autonomy.

Metacognition, defined here, refers to the knowledge gained by an individual of their own cognitive processes [7]. The importance and influence of metacognition in the learning process has been demonstrated and largely promoted in a literature revue [8]. We distinguish metacognitive knowledge – knowledge of one's own knowledge – from the knowledge of procedures tied to cognitive processes – metacognitive skills. Metacognitive skills or metacognitive capacity, corresponds to the procedural knowledge, which is necessary for a person to regulate and control their own learning activities [9–13]. In this study both aspects are associated through their theoretical attributes and the tools they use. However, it is the effect of metacognitive skills, which is the primary interest.

In order to gauge the possible effects of intervention program on the self-knowledge and autonomy of students it is necessary to firstly define these terms and determine their measurable aspects.

A commonly held belief seems to be that self-knowledge is an indicator of success. Each person possesses this knowledge, which may be better defined as a self-concept [14]. This concept of self is in fact multidimensional: the combination of different conceptions of self [15]. The concept of self, under its multiple forms, is retained in the memory and very much depends on the perception someone has of their lived

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experiences [14]. Whether it is real or not, a positive self-concept favors school performance [16]. Numerous studies supported this claim by showing a relation between a feeling of self-efficacy and academic achievement [17,18].

Another possible effect of the intervention program is the development of autonomy. Autonomy, in its primary sense, is the capacity to govern oneself according to one's own set of laws. Autonomy is variously defined, depending upon the field where the term is employed: philosophy, psychology and pedagogy. In this study, the educational field is of interest.

For Meirieu [19], autonomy consists in learning how to conduct ourselves. According to Linard [20] "autonomy is a higher level capacity, cognitive but also psychological and social, which involves the qualities of attention, self-control, intelligence, self-confidence and relational confidence, which few people initially possess".

Thus, calling upon knowledge, strategies and behaviors, integrated to attain school objectives, contributes to the development of autonomy. Resorting to these elements implies using certain executive functions (planning, self-control, flexibility…) that can be designated as self-regulation. The self-regulation of a system enables autonomy. According to Flavell, metacognition is tied to these executive functions of self-regulation: "Metacognition refers to one's knowledge concerning one's own cognitive processes and products or anything related to them […] the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects on which they bear, usually in the service of some concrete goals or objectives." [7]. Metacognition generally means a higher level of reflection in a way in which the learning of a task will be managed as an association of observational processes and evaluation [21]. Self-regulation, by way of this control on motivational and behavioral cognitive processes, enables better school success of students [22,23].

Thus, mobilizing metacognitive resources may contribute to better self-knowledge and may lead to a better self-concept. These elements are associated with establishing the self-regulation of the student's cognitive processes, in order to promote autonomy in learning and increased academic achievement.

Since our area of interest is adolescence, a crucial period of cerebral development, it is necessary to take this aspect into account. The neurophysiology literature points out a number of elements regarding cerebral activity in adolescence. Thus, even if one assists a reorganization of the neuronal connections and hence to a kind of neuronal 'pruning' in order to optimize a more flowing network which can be operationalized in adulthood, seemingly in order to limit elevated synaptic energy costs, this is an ideal period for the development and cerebral plasticity [24]. Cerebral plasticity starts at the start of life, enabling an individual to adapt himself to new experiences and to progress towards a coherent, functional stability in adulthood [25]. This period of adolescence is marked by a more important axonal myelination that leads to an increase in the speed of nerve influx and hence to efficiency [26]. This last point highlights the stabilization of axonal pathways [27] to be established in adulthood, but is accompanied by a synaptic dynamism which is more important than in adulthood [28].

A particular feature of adolescence is the immaturity of the prefrontal cortex, which among other things is characterized by cortical zone thinning [29], which leads to, for example, reduced cognitive control, or at least reduced regulation of attention [30]. Amygdala activity is also slightly different, which explains the raised emotivity during this period [31,32].

Taking this scientific knowledge into account enabled, at one and the same time, to construct teaching content more suited to this adolescent group and also to be able to inform them in a simple way as much about their behaviors and attitudes as about their learning potential and their academic achievement.

Finally, concepts to do with school and educational success need to be defined to both understand their multiple senses and in order to establish measurement methods for the intervention program and its analysis. The notion of success is often opposed to the notion of failure [33] in the educational system, especially in the French system, but the concept of success can often vary according to the interests and foci of the different parties. Whether it be for a student, a parent, a teacher, an administrator or even an institution, success is often viewed in the first instance as "academic achievement", understood as getting good results and professional qualifications. More precisely, having a school trajectory rewarded by the success of evaluations encountered throughout the course of a student's learning pathway in order to ensure the best cycles of superior study, leading now to a professional specialization with the ultimate aim of social success. The concept of success can be broadened to educational success, which though more blurred, could be adopted to reflect a better learning experience: the better acquisition of skills towards learning, or an orientation which enables students to achieve to the best of their expectations and abilities [34,35]. Thus, this is an extension of these concepts towards the expectations or perspectives of those concerned. Our intervention program will focus on these different aspects of educational success.

In order to measure the effects of this intervention based on the contributions of neuroscience, we proposed to conduct a study within the French school in New Caledonia, with 311 16-year-old students at the second level. This intervention program was a part of their school journey, with a tailored, mandatory course of 2h a week, titled "personalized support" (PS). This mandatory element has been in place in France since 2010, from the second level of the high school. Its aim is to support students in integrating to their new environment and seeks to provide methodological support, together with disciplinary strengthening and reflection on the direction of their studies. Thus, mainly through the methodological aspects of "PS", we have introduced neuroscience knowledge to the teaching content, mainly cognitive but also neurophysiological material, with the objective of measuring the impact of student uptake of such knowledge in their academic achievement.

This study, sought to measure the effects of the Neuroscience and Strategies in Education intervention program (NeuroStratE), based on the brain knowledge, on academic achievement of 16-year-old adolescents.

We hypothesized that this intervention based on metacognition would improve school results through better self-knowledge of students and their development of autonomy.

2. Method

2.1. The intervention program

The Higher School of Teaching and Education (ESPE) of the University of New Caledonia undertook the proposed intervention program (NeuroStratE: Neuroscience and Strategies in Education). Through the training followed, the teachers involved in the study were enabled to combine their knowledge of neuroscience with corresponding methodological skills, to be used in the teaching of their students. This neuroscientific knowledge is centered on cognitive and executive functions, in particular with regards to adolescence.

The project extended over two consecutive years, i.e. 2016 and 2017. It consisted of a preliminary study in 2016. Based on the findings of this first study, the intervention program was enlarged and modified in 2017 as detailed in Fig. 1. Eight second-level classes, holding around 30 students per class (n = 249: 129 girls, 120 boys) were involved in the program. Two classes acted as the control cohort (n = 62: 32 girls, 30 boys).

Participants gave informed written consent prior to their participation in the study, in line with legal requirements and the Declaration of Helsinki. The protocol was also approved by the Ethics Committee of the University of New Caledonia.

The first phase of the intervention program, consisted in the

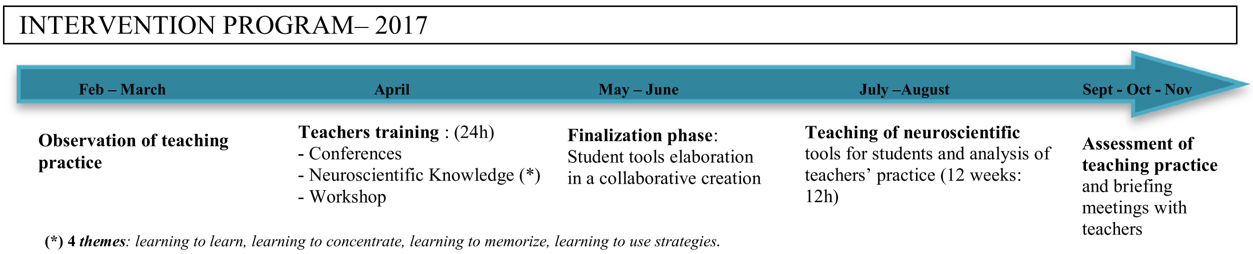

Fig. 1. Intervention program during the year 2017.

observation of teaching practice and the identification of the tools already elaborated in the teaching of “PS”. The second phase consisted in training the teachers, organized over 4 days, to a total of 24 h of training on the neuroscience contents including workshops where the tools that were subsequently used by students were elaborated. Four themes were addressed: learning to learn, learning to concentrate, learning to memorize and learning to use strategies. The third phase was the finalization of the tools to be used by the teaching team and focused on ensuring a consistent approach. The fourth phase consisted in the teaching itself, where the tools were used in a 12-weeks period, totaling 12 h per student. During each phase, the teaching sequences were video-recorded and analyzed. A fifth and final stage consisted in reflection by the team on how they felt about the project and its implementation.

The thematic elements centered on the main cognitive functions, attention and memory, as well as executive functions (planning, flexibility, cognitive inhibition, etc.). Thus we focused on: knowledge of the brain in order to identify barriers to learning (learning to learn); attention, which filters, selects and modulates information (learning to concentrate); memory, which encodes, stores and retrieves information (leaning to memorize); finally, experimenting and testing themselves, in order to plan and implement effective strategies (learning to put strategies in place). All these cognitive and executive functions are clearly tied to those necessary educational success envisaged in this study.

Teachers and students, explored the same themes, in terms of content but the approach to introduce was different.

The “learning to learn” theme was explored mainly by teachers and focused on metacognition according to the Büchel DELF program (“Discover your abilities, realize your possibilities, pave the way, be creative”) [36–39] and the Program of Instrumental Enrichment (PIE) [40] of Feuerstein.

For the students these 4 themes were delivered in 3 items. “Learning to concentrate”, requires knowledge of selective, sustained, alternating and divided attention. After teaching these theoretical elements, practical tools were given to them to promote their concentration in class. These tools are largely based on the work of Lachaux [41–43] as identifying the P.A.M. (Proposal for iMmediate Action), set up P.I.M. (Perception, Intention, Mode of action) and also with tools like the invisible gorilla experiment [44]. The "learning to memorize" part treated the memorization process: encoding, storage and retrieval and the different sorts of memory (immediate, short-term and long-term memory). The corresponding tools used [3,45], as the model of working memory proposed by Baddeley and Hitch [47,48]: phonological loop, visuospatial sketchpad, central executive and episodic buffer, for the working memory or the forgetting curve of Ebbinghaus [49] for the long-term memory and the need to organize the memorization of its revisions by a chronologic repetitions. The aspects of "learning to put strategies in place" were introduced by the theme of procrastination, which has meaning for students and allows to address two main elements: knowing how to manage time and knowing how to set goals, enabling to plan their own work. Among the tools used: the Pomodoro technique [50,51] or Eisenhower matrix [52]. In each theme, brain processes characteristic of adolescence was introduced, as well as executive functions, such as cognitive inhibition and control inhibition, based on Houdé's work [53,54].

Thus the teaching cycle spanned 12 weeks, to a total of 12 h. Each intervention comprised: neurophysiological et neurocognitive content; an activity allowing students to experience and test the theme; and finally the implementation of strategies which were evaluated from one week to the next. The objective of each class was to create the conditions for metacognitive learning (as the content of training courses "learning to learn") in:

- Challenging students with regard to their habits, performance, emotions, and utilization of strategies;
- Allowing them to put a name to their strategies and to guide them in making their strategies more effective, with a view to new knowledge;
- In particular, providing them the opportunity to experiment and test themselves, to evaluate and validate new strategies [36].

2.2. Measurement tools

2.2.1. The quantitative analysis

We used 2 sets of data:

1- The marks obtained by students within for each school subject by trimester before and after the program.
2- The scores from an evaluative questionnaire on the effectiveness of teaching adapted for this study [55].

Analyses of students' marks were conducted using R 3.5.1 with a significance level of $p = 0.05$. First, students' average marks were analyzed with their differences between control and test (Neuro) classes for each school subject and for each period (pre-test, test and post-test periods). Differences were tested with means equality tests (Student or Welch). The skewness and kurtosis were computed in order to decide about the normal distribution assumption.

Second, the students' average marks for each school subject were globally analyzed by an unbalanced mixed effects ANOVA for repeated measures. Period (pre-test, test and post-test) and group, i.e. class type (control or test), were considered as fixed effects, students and teachers were considered as random effects and students were considered as nested in the class type factor. Models were additive according to the results of the Tukey's additive test and we used sum squares Type II.

The scores from an evaluative questionnaire on the effectiveness of teaching adapted for this study [55]. According to the author, effectiveness of teaching may be evaluated over 4 levels: evaluation of the relevance of learning objectives, evaluation of acquired knowledge, evaluation of knowledge transfer and evaluation of impact. Learning objectives are relevant if they are constructed in such a way as to achieve the desired effect (here, academic achievement). Pedagogical effectiveness is defined as the attainment of competencies in line with teaching objectives. Knowledge transfer corresponds to the utilization of acquired competencies within the learning environment of students. The impact of learning is an advanced level that reveals the ability in using these competencies in new contexts, through an evolution of the initial organization of the program: this being the desired effect. Thus, impact = relevance + acquisition + transfer. This evaluation was undertaken via a post-test. The questionnaire, adapted from Gerard [55], allowed students to evaluate their learning through a series of questions on knowledge acquisition, relevance and transfer.

The validity of the measurement tool is based on that of the reference model. It has been used in several studies [56–58] by demonstrating empirically its content validity.

The tool explores several dimensions, thus its reliability, as internal consistency, cannot be studied. Nevertheless, Cronbach's alpha coefficient was calculated for each of the three dimensions investigated: relevance: 0.73; knowledge acquired: 0.48; transfer: 0.79. Given the very small number of items evaluating each dimension, it is possible to consider these coefficients as an evidence of the internal consistency.

2.2.2. The qualitative analysis

The qualitative analysis was about the students' opinions of the contents [59] of the intervention program, through the above questionnaire, with the questions: 1-"Indicate the positive points of this training"/ 2- "Indicate the negative points of this training". In addition, the 8 teachers were interviewed about the program with a specific question: “How and in what way do you think the Neuro PS module that you delivered this year, with a neuroscientific approach (knowing one's brain in order to enhance learning), could contributed to the educational success of your students?”. Each interview lasted 30 min.

The analysis of qualitative data was undertaken in 3 phases: the pre-analysis, the content study, and the analysis of findings and its interpretation. The pre-analysis is a somewhat intuitive stage and involves a preliminary reading to determine overall fields of investigation, which would lead to categorization of data [59–61]. In the second phase, the themes are defined and a determination is made of any sub-themes present. This is achieved through identification of associated keywords listed on a grid. The analysis follows a specific logical sequence to ensure internal coherence: word-to -word matching, sentence-to-sentence, ideas to ideas, etc. The third phase involves the interpretation of the data categorized under these themes and sub-themes, which can be achieved through simple statistical operations (percentages) providing precise information to supplement the initial quantitative analysis.

3. Results

3.1. Students' average marks

Fig. 2 shows the distributions of the students' average marks for each school subject, by period and group, i.e. class type (Neuro vs. control). In the subject ‘Mathematics’, the Neuro group achieved stable school results along the year whereas the control group achieved lower results during the test period and little improved results in the post-period. In ‘Physics and Chemistry’, both groups achieved stable results along the year but the results of the control group were a little lower during the test and post-test period. The Neuro group achieved better results in every period. In ‘Life and Earth Sciences’, the Neuro group achieved stable results along the year whereas the control group achieved lower results during the test period. The Neuro group started with results lower than the control group and finished with results equivalent (but higher) to those of the control group. In ‘History And Geography’, both groups achieved equivalent results during the pre-test and post-test periods and the Neuro group achieved better results during the test period. The results of the control group were stable whereas the Neuro group showed little improvement in the results during the test period. In ‘French’, the Neuro group obtained higher results during the pre-test period, with the difference decreasing over the year. In ‘Living Language 1’, the Neuro group started with results a bit higher than the control group but differences decreased over the year due to an improvement in the control group's results. In ‘Living Language 2’, results were stable in both groups and even though differences decreased over the year the control group achieved better results at every stage. In ‘Physical Education (PE)’, the results of the groups were largely equivalent, except during the test period where the Neuro group achieved slightly higher results.

Table 1 shows the Student's and Welch's t-tests when comparing average marks in both the studied groups, i.e., class type (Neuro vs. control), by school subjects, and by period (pre-test, test and post-test period). No significant differences can be shown with these tests, except in ‘French’ and ‘Living Language 2’, for the pre-test period ($p = 0.014$ and $p = 0.006$, respectively), in ‘Physics and Chemistry’ and ‘History and Geography’ for the test period ($p = 0.004$ for both) and in ‘Physics And Chemistry’ for the post-test period ($p = 0.013$).

The results of the ANOVA (Table 1), incorporating teacher and period effects, reveal no significant differences between both studied groups ($p > 0.05$ in every school subjects).

Finally, students' average marks showed no significant difference between the Neuro and control groups.

3.2. Self-evaluation analysis

This questionnaire receives the opinion of 212 students. They are grouped in two tables (Table 2 and 3). The median value of 2.5 provided an effectiveness threshold. With regard to the variation coefficient, which corresponds to the ratio between the standard deviation and the mean score, it is estimated that less than 15% were in agreement, while over 30% were in disagreement [62,63]. The analysis of mean scores for each question (Table 2) showed that only questions 1, 2, 3, 4 and 10 resulted in a score over 2.5. This indicates an overall satisfaction with student learning. Questions 5, 6, 7, 8, and 9 resulted in mean scores below the median. These could thus be considered as areas of difficulty in student learning: students have been neither able to use their new knowledge (knowledge transfer).

The questions allowed us to investigate three criteria of evaluation: relevance of the objectives, the knowledge level attained, and knowledge transfer (Table 3). It is noted that the intervention program was shown to have good relevance with regard to its objectives, with a score of 2.65, as well as to teaching effectiveness. With regard to the latter, acquired knowledge is situated above the median with a score of 2.72, with relevance scoring 2.65. In contrast, the score for knowledge transfer is 1.88, lower than the median. Therefore there is neither internal nor external transfer. The responses from students thus showed they value learning, which is in line with their needs (relevance), allowing them to acquire the targeted skills, which however, are not transferred to other contexts. The combination of the three criteria, following to the formula put forward by Gerard [55], indicated that the education had no impact. This corroborates the results in terms of improvement in academic achievement. In this way the measurement tool allows for a finer analysis of the quantitative data with regard to the marks obtained by students over the year: it shows that despite the education resulting in a good level of knowledge acquisition in line with objectives, considered as relevant, the learning was not used or transferred.

3.3. Analysis of student responses on the intervention program

The self-evaluation by students who followed the program, comprised an open-ended question on the positive and negative aspects of the program, at the end of the questionnaire (1-"*Indicate the positive points of this training*"/ 2- "*Indicate the negative points of this training*").

The different responses have been categorized and referenced in two tables (Table 4 and 5) showing ideas expressed as percentages.

On the positive side, 36.8% of student responses showed the acquisition of new knowledge, 56.6% the acquisition of new methods and new organizational skills, and 37.4% personal attributes expressed under the form of competencies linked to the personal development of students.

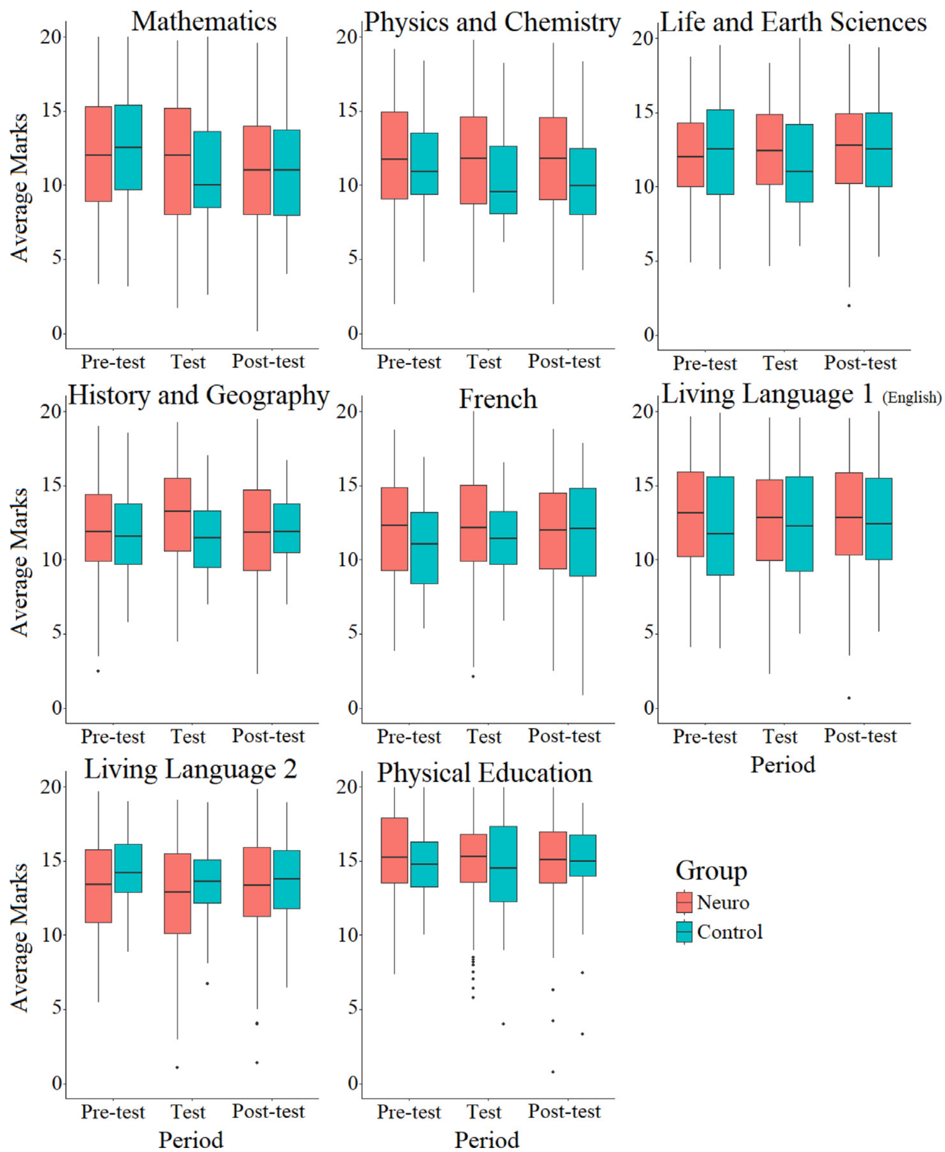

Fig. 2. Boxplots of students' average marks between 0 and 20 points per school subject during pre-test, test and post-test periods in 2017.

On the negative side, aside from the learning conditions, seen to be too late in the day or too long by 32.9% of students, 20.7% gave a negative response on the contents, seen to be insufficient, and 28.4 mention problems related to the animation of the courses, in fact the lecturing techniques. Finally, 18.1% of students said that they were not able to put their new knowledge and skills to use either because of difficulties in changing their habits regarding the new tools or because the supports were not useful.

A close reading of the results seems to indicate that the activities were above all the transmission of knowledge – viewed as interesting for some students, boring for others – but not strongly orientated toward the development of tools and strategies, which might explain the difficulty in transferring the acquired knowledge.

3.4. Analysis of contents of teacher interviews

The analysis of contents with regard to the teacher interviews, having verified the intervention program vis-à-vis students, showed a convergence of views, itemized in Table 6. The views of teachers on the intervention program showed a positive impact but one which did not translate into an improvement in marks over the school year. These views explained the non-improvement in school results by the fact that the methodological tools presented to students were not being put into practice, in particular because the second level class, being not too difficult, the already advanced students not seeing the necessity to change their established work methods and the weaker students not having sufficient motivation to acquire and use these new work habits. The teachers on the other hand saw a positive impact on students, by virtue of the fact that the established methodological tools have a scientific basis and by the increased self-knowledge attained through an understanding of their brain function and associated cognitive and physiological mechanisms. These elements contribute to better self-knowledge and reassurance during this delicate period of adolescence.

4. Discussion

This study allowed us to measure the effects of cognitive neuroscience contributions within a 12-weeks-teaching program to students aged from 16 entering upper high school in the French education system. Even though the school results are not statistically different between the Neuro and the control group, the Neuro group proved to be more efficient, better organized, and improved their ability in planning their learning activities over the course of the program. They also felt themselves to be more self-reliant and confident in their studies.

Table 1
Students' average marks per school subject during the three periods (pre-test, test and post-test) in 2017. Results of the unbalanced mixed effects ANOVA for repeated measures for the three studied periods with the control and the Neuro groups (*n* = 264)

School subject	Group	Pre-test period				Test period				Post-test period				ANOVA[a]
		Skewness	Kurtosis	Mean ± SD	*p*-value	Skewness	Kurtosis	Mean ± SD	*p*-value	Skewness	Kurtosis	Mean ± SD	*p*-value	*p*-value
Mathematics	Control	−0.128	−0.568	12.4 ± 3.88	0.639	0.055	−0.425	10.7 ± 3.84	0.161	0.265	−0.719	11.0 ± 4.02	0.862	0.933
	Neuro	−0.019	−0.947	12.1 ± 4.06		−0.183	−0.938	11.6 ± 4.36		0.061	−0.730	11.1 ± 3.98		
Physics Chemistry	Control	0.203	−0.676	11.5 ± 3.19	0.403	0.730	−0.340	10.4 ± 2.89	0.004	0.522	−0.344	10.5 ± 3.29	0.013	0.508
	Neuro	−0.027	−0.842	11.9 ± 3.62		−0.116	−0.824	11.8 ± 3.74		−0.031	−0.793	11.8 ± 3.60		
Life and Earth Sciences	Control	0.074	−1.035	12.7 ± 3.93	0.278	0.476	−0.692	11.6 ± 3.64	0.107	−0.116	−0.625	12.4 ± 3.41	0.960	0.672
	Neuro	−0.117	−0.487	12.0 ± 3.05		−0.027	−0.751	12.4 ± 3.18		−0.383	−0.209	12.4 ± 3.30		
History Geography	Control	0.242	−0.756	11.8 ± 2.92	0.413	0.225	−0.804	11.6 ± 2.57	0.004	−0.073	−0.623	11.9 ± 2.35	0.855	0.741
	Neuro	−0.193	−0.077	12.2 ± 3.24		−0.383	−0.642	12.9 ± 3.11		−0.063	−0.678	12.0 ± 3.56		
French	Control	0.076	−1.169	10.9 ± 3.20	0.014	−0.092	−0.716	11.4 ± 2.50	0.057	−0.607	−0.377	11.6 ± 3.97	0.564	0.313
	Neuro	−0.027	−0.948	12.1 ± 3.38		−0.234	−0.296	12.2 ± 3.61		−0.182	−0.692	11.9 ± 3.51		
Living language 1 (English)	Control	−0.039	−1.141	11.9 ± 3.96	0.053	0.015	−1.137	12.1 ± 3.73	0.262	0.005	−0.793	12.7 ± 3.44	0.740	0.969
	Neuro	−0.255	−0.845	13.0 ± 3.73		−0.281	−0.558	12.7 ± 3.87		−0.218	−0.427	12.9 ± 3.70		
Living language 2	Control	−0.194	−0.649	14.4 ± 2.53	0.006	−0.128	−0.150	13.6 ± 2.68	0.080	−0.381	−0.372	13.7 ± 3.13	0.473	0.255
	Neuro	−0.148	−0.745	13.2 ± 3.17		−0.254	−0.389	12.8 ± 3.47		−0.391	0.092	13.3 ± 3.45		
Physical Education	Control	0.079	−0.336	14.8 ± 2.12	0.065	−0.267	0.030	14.7 ± 3.47	0.574	−1.680	4.238	14.8 ± 2.71	0.647	0.201
	Neuro	−0.250	−0.538	15.4 ± 2.72		−0.714	0.668	15.0 ± 2.81		−1.048	3.104	15.0 ± 2.82		

[a] Unbalanced mixed effects ANOVA for repeated measures adjusted by random effects (students and teachers).

More precisely, the global analysis of the students' marks did not provide evidence that the NeuroStratE program had a direct effect on school results (Table 2 and Fig. 1). However, significant differences were demonstrated between both groups in French, Leaving Language 2 during the pre-test period, in Physics and Chemistry during the test and post-test periods, as well as in History and Geography during the test period (Table 1). These significant differences observed during the pre-test period cannot be due to the learning program but this may rather reveal differences in school level, in teachers' methods or in marks given by teachers for some school subjects between both groups in the pre-test period. Moreover, as there are very few instances with significant differences during both test and post-test periods, these differences might be due to factors other than class group.

These aspects are confirmed by teachers who noted in their interviews no significant improvement in the results of their students (Table 6).

In order to explain these results several elements need to be taken into account: owning and applying the neuroscientific tools by students and thus the length of the program; lecturing techniques, and the appropriation of the cognitive neuroscience knowledge by the teaching team.

4.1. Owning and applying the neuroscientific tools by students and the length of the program

Even though there was no real improvement seen in students' results, specific elements can be gleaned from the questionnaire (Table 2). That is, even if there is no significant impact of the NeuroStratE program on student learning, due to the absence of knowledge transfer demonstrated through analysis, the questionnaire provides important, specific insights (Table 3). It was observed that students acquired knowledge and that the program was relevant for them (Table 3). These elements were entirely supported by the analysis of student feedback (Tables 4 and 5). Indeed students noted that they acquired some knowledge and strategies. On the other hand they noted that they did not always use them. This confirms the absence of knowledge transfer and thus the absence of any significant impact of the program in this regard (Table 3). Students justified their non-utilization of the knowledge, hence knowledge transfer, by the fact that they already had study habits relevant to their needs at this level or that it would be too much of an effort to make any changes to their habits (Table 5). These elements were also observed in the analysis of teacher interviews (Table 6). They noted that students did not really implement the tools. On one hand the better students already possessed study habits even if they felt the tools were useful, on the other hand the students having difficulties were not sufficiently motivated to use the new tools.

The length of the program (12h of teaching), and hence the time required to integrate the tools, may be a factor which explains these findings; an important element supported by both students and teachers is changing habits (Tables 5 and 6). It seems difficult to be able to achieve a significant impact, notably on school results, in so little time. Changing habits and putting new practices in place is mentally demanding, requiring repetition [64,65] and especially motivation [66]. The reward system, which implicates the ventral striatum and dopamine, seems slightly different in adolescence; in effect the threshold of stimulation (type of task, context, importance of the reward) is more elevated than in adulthood, as is the intensity of the response [67].

Thus, even if this period of adolescence is geared towards learning in terms of cerebral functioning, the reward system for this age group requires the more important element of motivation in order for new habits to be instilled. Students need to find real motivation to change their way of doing things and introduce new processes, and to anchor them through repetition. The feedback received from students and teachers revealed that motivation, whether extrinsic or intrinsic – all-important for change to occur, was absent in students. With some justification then students were not able to see the usefulness of new

Table 2
Results in percentages for each question, mean score, standard deviation and variation coefficient

Questions	Not at all / A bit / Satisfying / Very satisfying	Mean score	Standard deviation	Variation coefficient (%)
1 – How do you feel after the neuroscience PS?	7% / 23% / 63% / 8%	2.72	0,70	25.8%
2 – Do you think the PS courses you received in neuroscience are interesting for your school success?	12% / 36% / 39% / 14%	2.54	0.87	34.3%
3 – What are the most relevant courses in this training?	(Multiple answers allowed)	2.76	1.08	39.3%
4 – Are you satisfied with the courses proposed in the neuroscience PS?	6% / 22% / 62% / 10%	2.75	0.71	25.8%
5 – Did the knowledge provided during the neuroscience PS courses help you to be more effective for managing your personal work?	26% / 56% / 17% / 2%	1.93	0.69	35.8%
6 – Did the knowledge provided during the neuroscience PS courses help you to be more effective for memorizing your courses?	25% / 56% / 17% / 3%	1.98	0.72	36.7%
7 – Did the knowledge provided during the neuroscience PS courses help you to be more effective during your knowledge assessments (exams)?	34% / 47% / 17% / 3%	1.896	0.790	41.7%
8 – Do you use what you learnt in neuroscience in other courses than the PS?	23% / 14% / 56% / 7%	2.05	0.80	39.5%
9 – Do you use what you learnt in neurosciences outside school, during your day-to-day life (family, sport, cultural,…)?	45% / 40% / 10% / 5%	1.54	0.74	48.2%
10 - Do you think the neuroscience PS course should be offered next year to the second year class?	NO 15% / YES 85%	2.78	0.96	34.5%

Table 3
Questions and indexical scores[a] associated with each level (relevance, knowledge acquired and knowledge transfer) measuring the raw and relative impact of the NeuroStratE intervention.

Index	Questions	Raw	Relative
- Relevance	2.4	2.65	54.95%
- Knowledge Acquired	1	2.72	57.39%
- Knowledge Transfer	5,6,7,8,9	1.88	29.37%
- Knowledge Transfer	*Internal* (5-7)	1.94	31.24%
	External (8-9)	1.80	26.57%
Impact		2.42	47.24%

[a] The raw score corresponds to the average of the results of the questions concerned, on a scale from 1 to 4. The relative score corresponds to this raw score transformed into a percentage.

strategies or were not sufficiently motivated to implement them.

4.2. Lecturing techniques, and the appropriation of the cognitive neuroscience knowledge by the teaching teams

Each teacher was required to incorporate the teaching materials collaboratively developed, with their own teaching methods, having a variable level of mastery of the elaborated contents. The teaching practices were analyzed, although they have not been detailed in this paper; they revealed a diversity of lecturing techniques. This fact is corroborated by the negative feedback of students (Table 5) who found that the contents, presentation or other tools needed improvement (28.4% of students surveyed). It could be hypothesized that the lecturing techniques played a role in the transmission of knowledge and especially on the uptake of proposed strategies. This could explain the differences observed in Fig. 2 and Table 1 in students' average marks for different school subjects, as in Physics and Chemistry, for the test and

Table 4
Analysis of the contents on the positive aspects of the program (general approach, methods and self-contribution), number of responses and percentages.

212 participants, 179 responses

	Number of responses	Expressed as %
No positive opinion[a]	49	23.1%
Positive opinion by category[b]		
Learned new knowledge	39	23.9%
Understood brain function	21	12.9%
Acquired new methods	33	20.2%
Being more effective	15	9.2%
Being more organized	19	12%
Helpful	15	9.2%
Helpful for others	9	6%
Personal attributes:	61	37.4%
-Self confidence	8	13.1%
-Motivation	5	8.2%
-Self-knowledge	38	62.3%
-Autonomy	10	16.4%

[a] Over total number of participants.
[b] Over the number of responses received.

Table 5
Analysis of the contents on the negative aspects of the program (learning conditions, presentation of material, content, putting on the practice), number of responses and percentages.

212 participants, 155 responses

	Number of responses	Expressed as %
No negative opinion[a]	76	35.8%
Negative opinion by category[b]		
On the learning conditions		
Too long	19	12.3%
Too late in the day	32	20.6%
On the presentation of material		
Boring and/or repetitive, lacks dynamism, technical difficulties	44	28.4%
On the content		
Knowledge already held	17	11.0%
Not enough information on method or application too short, quality of handouts	15	9.7%
Putting into practice		
Leads to change of habits	13	8.4%
No interest and not useful	15	9.7%

[a] Over total number of participants.
[b] Over the number of responses received.

post-test period. The teachers were themselves learners: they do not have specialist knowledge in these scientific taught topics, something that may have resulted in a discomfort or even a feeling of a lack of credibility. This point emerged in the teacher interviews (Table 6) and the briefing meetings, as well as observed through teaching practice. These elements: lecturing techniques and incomplete mastery of the content may also explain the results of the NeuroStratE program were not found statistically significant with regard to student results over the year.

4.3. Student autonomy and self-knowledge

The analysis of student feedback (Tables 4 and 5) confirmed and highlighted the results from the questionnaire. Although the acquisition of new knowledge and strategies appeared other interesting elements emerged. Through the feedback and observation of students it was noted that the program contributed to personal development. There was an overall satisfaction with the program, with students noting that they thought themselves to be more efficient, better organized, and improved their ability in planning their learning activities. They especially thought themselves to be more self-reliant, better motivated and confident, with greater self-knowledge (62.3% of students surveyed, Tables 2 and 4). In this regard the teaching NeuroStratE program conducted through this study proved to be an educational success [34,35]. Even though the length of the program did not allow for any change in usual study practices it is noted that better self-knowledge leads to a better self-concept and thus contributes to a feeling of self-efficacy [14,16,18]. In the long term this may affect school results and have a positive influence on a student's progression. Thus a longer period of application of the NeuroStratE program would likely lead to changes in student habits and this is a future research hypothesis.

5. Conclusion

This complex study through a metacognitive approach on students aged from 16 did not show any significant effect on academic achievement but did show that such an intervention program can contribute to fundamental competencies such as self-reliance and self-knowledge. These findings are mainly associated with the difficulty in establishing new study practices for adolescents in a so short time period. The results may be explained by the way teachers who were themselves learners in innovative practices based on neuroscience framed the program. The impact, which could have been highlighted by the program NeuroStratE, concerns the acquisition of new knowledge and study practices in students. These factors are influenced however by a greater sense of self-reliant, better self-knowledge and hence a better self-concept, leading to a feeling of self-efficacy. These aspects are finally more important for the education of these adolescent students in terms of how they construct themselves and the potential for their educational success.

6. Future research prospects

In order to follow up this research project, knowing these findings it may be interesting to assess the impact of a similar program on younger primary school students or young adults at university; that is the impact on students who fall outside the adolescent age range. Other elements may also be studied, for example the influence of specialist teachers or using tools directly developed by teachers within their own training. Moreover, a longer period of NeuroStratE program should be

Table 6
Analysis of contents of teacher interviews (impact, transfer, acquired knowledge, self-contribution), number of responses and percentages.

8 participants, interview 30 minutes

	Number of responses	Expressed as %
Positive impact but without improvement in school results	6	75%
Interesting to students but little to no practical application	5	63%
° *The weaker students lack motivation*		
° *The better students already possess their own methods*		
Provides scientific validation for methods already known	7	88%
Leads to better self-knowledge, understanding, demystification and reassurance through physiological explanations	8	100%

considered, for example, throughout a school year associated with specific neuroscience teaching of one to two hours per week. Other aspects that could be studied: diagnose the difficulties of the students before the training and set up adapted and specific teaching contents for these students, on the basis of neuroscience knowledge, could improve their motivation. Thus it may be possible to observe whether the hypotheses are supported regarding student learning habits, or at the scientific level whether the lecturing techniques used by teachers do indeed affect students' results. Finally, the approach of the study is metacognitive, as a consequence measuring metacognition with adapted instruments [68], before and after training between the Neuro and the control group, could bring interesting elements that would complete the study about this aspect. As well as, we could measuring the evolution of executive functions (as planning or inhibition), using appropriate tests, as Tower of Hanoï task (TOH) or Tower of London (TOL), before and after training between the Neuro and the control group.

Ethical statement

The project extended over two consecutive years, i.e. 2016 and 2017. It consisted of a preliminary study in 2016. Based on the findings of this first study, the intervention program was enlarged and modified in 2017 as detailed in Fig. 1. Eight second-level classes, holding around 30 students per class (n = 249: 129 girls, 120 boys) were involved in the program. Two classes acted as the control cohort (n = 62: 32 girls, 20 boys). The thematic elements centered on the main cognitive functions, attention and memory, as well as executive functions (planning, flexibility, etc.). Thus we focused on: knowledge of the brain in order to identify barriers to learning (learning to learn); attention, which filters, selects and modulates information (learning to concentrate); memory, which encodes, stores and retrieves information (leaning to memorize); finally, experimenting and testing themselves, in order to plan and implement effective strategies (learning to put strategies in place). All these cognitive and executive functions are clearly tied to those necessary educational success envisaged in this study. Participants gave informed written consent prior to their participation in the study, in line with legal requirements and the Declaration of Helsinki. The protocol was also approved by the Ethics Committee of the University of New Caledonia.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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