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Knowledge of neuroscience boosts motivation and awareness of learning strategies in science vocational education students

Neuroscience boosts motivation and strategies

Marcel Ruiz-Mejias[1,2*], Nora Pérez[1], Mar Carrió[1]

[1] Research Group in Health Sciences Education, Department of Experimental and Health Sciences, Universitat Pompeu Fabra, Dr. Aiguader 88, 08003 Barcelona, Spain
[2] Escola Pia de Sarrià-Calassanç, Immaculada 25-35, 08017 Barcelona, Spain

*** Correspondence:**
Marcel Ruiz-Mejias
marcel.ruiz@upf.edu

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MR-M designed intervention and research, performed quantitative and qualitative data collection, analyzed data, wrote and edited the manuscript. NP performed statistical analysis on MSLQ-55. MC designed research and edited the manuscript.

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Abstract

Interest in how neuroscience can support education has grown over the last few years. Based on the concept that neuroscience can help to tailor education, we carried out a workshop-based intervention for young adult students, with the goal of impacting their self-concept as learners. We surmised that educating participants about brain structure and function, and about the nature of learning, may change how students perceive themselves and elicit a positive mindset for learning situations. The aim of this research was to transform students' self-concept, enhance their motivation, and provide them with useful tools for their education and long-life challenges as learners. For this, the MSLQ instrument and qualitative students' assessment was used to collect data before, immediately after and 10 months after the intervention. Our results show that a program about neuroeducation and learning strategies, directly impacted student motivation. Also, students reported long-term use of such tools. We conclude that similar interventions may be useful in different learning contexts to help students become aware of self-motivation and the strategies they use, and thereby more effective learners.

Keywords: self-concept, neuroscience, learning strategies, metacognition, neuroeducation, student motivation, nature of learning, vocational education training

Introduction

Motivation is a strong promoter of learning and is closely related to the strategies that learners choose to achieve learning. Motivated-learning strategies, as well as student success during schooling, are highly dependent on each student's self-concept about her/his capacities in relation to this naturally inbuilt brain process[1-5]. The way in which students perceive themselves in learning situations directly relates to achievement, presumably via the construction of a mindset that allows and predisposes for it. In this scenario, neuroscience may be used as a tool to initiate a path for exploring their bodies internally; to become conscious of the biological substrates of their learning capacities; to transform their vision of themselves when they face challenges at their learning centers (and in life in general); and to place them in a positive mindset that can sustain motivation. Thus, neuroscience research can increase self-awareness by giving students a framework that provides evidence about key aspects of effective learning. Two such key aspects are metacognitive strategies, which generate specific brain activity[6,7], and the widely studied critical involvement and management of emotions in learning. Thus, giving students access to different aspects of how the brain functions may open a path to changing and ameliorating their transitions across formative stages. The main objective of this training would be to enhance motivation and help students choose better strategies to improve their learning and results, in the same way as an athlete who has intimate knowledge of her or his body's capacities can increase performance, or a patient with diabetes who has knowledge about the disease can better manage it. Given our increasing knowledge about the structure and function of brain circuits involved in learning, neuroscience may support pedagogical or learning theories in an educational context. Indeed, how the suitability of the constructivist model connects to the neurobiology of the learning brain is explained well in the literature[8-10].

Knowledge of neuroscience therefore has the potential to modify student perception of their capacities for learning. This has been exemplified in the past decade in several works, including that of Dweck and colleagues, who documented in several publications how interventions based in the knowledge of neuroscience can change beliefs about intelligence, and how this can be turned into school achievement[11-14]. In these studies, students changed their perception of intelligence as an innate and invariable capacity to that based on a flexible capacity that can be fine-tuned and strengthened[12]. Notably, they identified the educational contexts that sustained the effects of the growth mindset intervention[14]. This intervention delivered broad knowledge in neuroscience and neurobiology of learning to the students, including study skills for which it is difficult to attribute specific elements as being critical to the development of a flexible mindset; nonetheless, the study also showed a strong impact on student motivation. That said, it is important to corroborate whether these changes in beliefs as effective and long-term persist. Further, by studying results from a neuroscience course for young secondary students that was also based on workshops, Devonshire and colleagues likewise concluded that intelligence can be improved by reinforcing evidence-based knowledge about the brain[15]. The content of these workshops included neuroplasticity, the role of emotions in learning, cellular neuroscience, and others. Students reported any changes in their belief about the nature of intelligence up to 20 months after the intervention (albeit with no distinction of changes due to motivational measures or academic performance). Of note, young adult learners can also benefit from changing their beliefs trough knowledge of neuroscience interventions, using for instance training in incremental intelligence, as a study by Aronson and colleagues demonstrated in college students[16], using Gardner's multiple intelligences theory[17], which despite spreading the misunderstood idea of the existence multiple intelligences, it may be a valid perspective for orienting teaching practices in terms of multiple skills.

The choice of motivated strategies for learning may also highly relate to how students self-regulate the process, where effort regulation or metacognitive self-regulation have an impact on school success[18,19]. Notably, metacognitive strategy use can affect motivational beliefs on effort regulation[20]. From this point of view, training in knowledge of neuroscience may arise as a fertile scenario in which metacognitive strategies can be grounded when taught. These strategies are a current focus of interest in multiple educational policy systems worldwide, including the EU (see NMC Horizon Report[21]). Strong evidence supports a specific benefit to learners who use metacognitive strategies[18], with effects reported in several meta-analyses[22-25] and in the impact of metacognitive scaffolding in learning[26]. Interestingly, successful students more often report the use of metacognitive strategies[27,28], whether or not they were aware of the term "metacognition". On the other hand, underperforming students rarely report such metacognition strategies when asked[29]. Thus, evidence of how the brain learns can in turn provide a framework to explicitly teach metacognitive strategies in a meaningful way.

Our hypothesis is that by training students about knowledge in neuroscience, the nature of learning and its biological basis, they themselves will transform their self-concept, increase their self-awareness, enhance their motivation, and use more effective learning strategies. The aim of this approach is to help students become more effective learners. For this purpose, we conducted a quantitative and qualitative research with science vocational education students to assess the impact on these key aspects of learning after their involvement in a neurobiology workshop.

Methods

Design and Participants

Twenty-nine health students in science vocational education training from a school in Barcelona (Spain) participated in this research. A pre-/post-course design was used, with questionnaires given at one week before the course (pre-) and at one week following the last session (post). Follow-up data were collected at 10 months after the intervention was performed. Socioeconomic profile was diverse, they were first-year students, and ages were between 18 and 23 years old. The gender ratio of the class was 16 females and 13 males, thus 15 females and 11 males participated in the quantitative data collection trough CMEA-55 in the post-course measure.

Intervention

The intervention, which we called the *NeurAula* program, comprised eight sessions over two months (see **Table 1**) and included four talks by expert neuroscientists, two participatory activities, and a two-session workshop on metacognition and neuroeducation. The program was delivered within the class schedule, although it was extracurricular content. The neuroscience content of the intervention was broad, but mostly focused on the neurobiology of learning. Different aims were defined for each activity (**Table 1**). Most sessions were dynamic and participatory, while three of the four talks were given in a masterclass format with an open space for questions at the end.

Table 1. NeurAula program

Session	Title	Main objectives and contents
Talk 1 (1h)	Levels of activity in the brain: From single neurons to networks	Introducing the main types of activity related to learning
Talk 2 (1h)	Biology of learning and animal/ human learning experimentation	Biological basis of learning and debate about research and ethics in learning
Talk 3 (1h)	Virtual reality and brain mechanisms of perception	Introducing brain perception mechanisms and illusions Recruiting interest in the application of 3D animation to videogames
Talk 4 (1h)	Neuroscience and education	Introducing features of brain function and their implications in education (e.g. neuroplasticity, brain development at childhood, connectivity, emotions in learning)
Poster session (1h)	Presenting a paper on neuroscience and learning	Generating interest in research of the neuroscience of learning Oral communication skills
Role-play (2h)	Ethics of neuroenhancement	Neuroenhancement: Ways to improve brain function and learning, as well as their bioethical aspects
Workshop (3h)	Neuroeducation and metacognition	Introducing brain function features related to education and self-reflection about the learning process (e.g. creative problem solving, the social brain, learning by playing games, metacognitive strategies)

Session descriptions

Talk 1. The first talk provided content and evidence about the levels of activity of the brain, from the structure and activity of a single neuron to synchrony in waves and network activity in the brain. It also included explanations about the specific function of several brain regions, including the hippocampus, thalamus, and frontal cortex, and linked cognitive functions to those areas. The talk also included data demonstrating the activity of specific neurons in the hippocampus, such as in the place cells. Finally, some content was given about the role of neurotransmitters in the brain, such as glutamate, GABA, and dopamine.

Talk 2. This talk was developed as a dynamic seminar in which the expert established a debate among the students whilst delivering content on several topics around the neurobiology of learning, as well as on animal experimentation and human experimentation in learning. The expert described different types of learning mechanisms that are biologically built into humans and animals. After this, a debate on ethical aspects of animal experimentation was performed.

Talk 3. A talk on virtual reality was given, which revised the current knowledge in which this technology relies on tricking the brain and creating illusions based on sensory information. The aim of this session was to show how learning could be achieved in simulated and secure contexts. Some concepts in the field were presented and discussed, such as presence and immersive environment. The talk included examples in which this technology has been used for research, including mental illness, phobias, social studies, and gender violence.

Talk 4. The last talk delivered content on the specific relationship between neuroscience and education. Several brain developmental aspects were covered, including the generation of learning through brain connectivity, the implication of positive emotions in the construction of knowledge, and the role of motivation in promoting learning. Topics including the diversity of brain capacities, the role of neuroplasticity in shaping the brain, the importance of education in skill modeling, and the benefits of developing physical activity and creativity during schooling were also discussed.

Poster session. This activity aimed to promote interest in neuroscience and learning in students, as well as to tailor critical online searches and oral communication skills. With the orientation of the teacher, students had to select a paper in neuroscience/learning/neurological disease, read it, select the main information, create a poster, and defend it in a session; a prize for the best presentation was then presented. Students were grouped in pairs for the oral presentation, although some of them did it individually.

Role-play. This 2-hour session created a learning scenario in which students had to defend opinions from a predefined role, even if these did not coincide with their actual opinions. The discussion topic was about neuroenhancement and covered several issues, with a general aim of highlighting the benefits and risks of it. The role-play was supported with PlayDecide materials.

Workshop on metacognition and neuroeducation. An expert presented content on different aspects of how the brain deals with learning in an educational context. The workshop also included activities in which students tested the strategies of active learning in pairs, in groups or with the whole class. The content included the social brain, metacognitive strategies, creative problem-solving, and outside-the-box thinking. The expert proposed activities, such as games with body movement, to the whole class for executive function learning, peer learning and reflection after presentation of perception brain tricks, and generation of creative solutions by students in front of apparently unresolvable problems.

Instruments to Assess the Intervention

The impact on motivation and learning strategies was assessed using both quantitative and qualitative methods. A validated test (CMEA-55) was used to determine the impact on the students' motivational strategies immediately after the intervention. In order to explore the students' perceptions of the usefulness of the intervention, their reflections were collected during the intervention, and two questionnaires were designed to analyze their opinions in the short term (after 2 weeks) and long term (after 10 months).

Motivated Strategies for Learning Questionnaire: A 55-item Spanish-translated version of the MSLQ-81 instrument (see **Supplementary Table 1**) was used as quantitative pre- and post-course data collection. It contained nine variables, six of which address the motivation dimension (intrinsic goal orientation, extrinsic goal orientation, task value, control beliefs, self-efficacy for learning and performance, and test anxiety), and three of which address the learning strategies (metacognitive regulation, time and study environment management, and effort regulation) of the original instrument by Printch and collaborators (for a manual, see[30]). The CMEA (*Cuestionario de Motivación y Estrategias para el Aprendizaje,* "Questionnaire for Learning Motivation and Strategies") was extracted from a doctoral thesis by Maria del Carmen Ramírez Orantes[31], in where the questionaire was validated in a Spanish speaking population of teenager and young adult students, similar the current study. The reliability values from the motivation scale as a whole was 0.88, and values for the three selected variables from the learning strategies scale (metacognitive regulation, time and study environment management, and effort regulation) were 0.77, 0.65, and 0.48, respectively (Cronbach Alpha), with 0.90 for the whole scale. The validity of the motivation scale as a whole was 0.920, and values for the three variables from the learning strategies (as above) were 0.828, 0.730, and 0.582, respectively, with 0.972 for the whole scale (Kaiser-Meyer-Olkin index). Pre-testing was done in one session in the week before of the 2-month intervention.

Student reflections: During the intervention, we created a blog site to promote the students' self -reflections about the activities. A description of the activities was posted on the blog and the students, in groups of 4-6, answered the following questions for each type of activities (talks, poster presentation and role-play, metacognition workshops): "How do you value the quality of the activity?" and "Did these activities have any impact on your learning?".

Post-intervention ad hoc questionnaire: We designed an ad hoc questionnaire to assess the impact of the intervention perceived by the pupils, delivered in a single session at one week after finalizing the intervention. It consisted of four items that addressed their interest and motivation, whether they improved their knowledge about how the brain works, and the usefulness and applicability of the intervention. Finally, students were asked to identify strengths and points to be improved, and to assess their satisfaction with the experience.

Follow-up ad hoc questionnaire: At ten months after the intervention, pupils answered a questionnaire to report their use of the strategies learned during the intervention and whether participation in the *NeurAula* project gave them an advantage for their learning. They had an open-ended field for their answers.

Data analysis
Comparison of the cohorts in the experimental design was analyzed with Wilcoxon Mann-Whitney U test for each of the variables from the CMEA-55 with R software. We compared separately pre- with post-course answers from the students in the class. Student answers from the post-course and follow-up ad hoc questionnaires (at one week and 10 months after the course, respectively) were extracted and analyzed, and some student comments were included in the qualitative analysis. The qualitative assessment from the blog site was analyzed separately by two researchers and then grouped into categories and sub-categories with the Atlas software, which helped to corroborate and better dissect the impact of the intervention. From all qualitative data collected, student comments were appropriately tagged as coming from the blog site (B#); the justification of their implication (Q#) in the post-course ad hoc questionnaire; the strengths/things to improve (I#), both in the blog site and the post-course ad hoc questionnaire; and the follow-up ad hoc questionnaire (F#). The comments were classified in categories and subcategories as depicted in **Table 2**, and also frequency-quantified.

Results

Impact of the NeurAula Program in the Motivated-Learning Strategies
Table 2 shows the results from the data collected in the CMEA-55. No differences in any of the variables were detected using Wilcoxon Mann-Whitney U analysis in the intervention group, although slight increases were observed in some variables, such as extrinsic and intrinsic goal orientation, task value, or metacognitive self-regulation.

Table 2. Impact of the intervention on the CMEA-55

	Intervention			
	Pre-course		Post-course	
	Mean	SD	Mean	SD
EXTRINSIC GOAL ORIENTATION	5.10	0.78	5.45	1.04
INTRINSIC GOAL ORIENTATION	5.10	0.92	5.33	0.90
TASK VALUE	5.66	0.95	5.87	0.83
CONTROL BELIEFS	5.12	0.80	5.19	0..88
SELF-EFFICACY FOR LEARNING AND PERFORMANCE	5.45	1.03	5.63	0.74
TEST ANXIETY	4.26	1.32	4.28	1.15
METACOGNITIVE SELF-REGULATION	4.40	1.15	4.46	1.22
TIME AND STUDY ENVIRONMENT	4.95	0.88	4.89	1.00
EFFORT REGULATION	4.82	1.13	4.79	1.41

Student Assessment of the NeurAula Program

The results of the post-course ad hoc questionnaire provided insight into the student perception of it, and how it impacted their motivation for participating in the project. Answers to the quantitative questions showed a good acceptance of the intervention. When students were indirectly asked about whether they felt motivated within the project, 80.8% reported being motivated and felt involved because they found the subject to be interesting. Notably, 92.3% of students responded that the intervention improved their knowledge about how the brain works in learning. In addition, 80.8% reported that the knowledge presented in the program was useful, although only 26.9% reported being aware of using any learning strategies presented in the *NeurAula* program (**Figure 1**). To aid in describing the quantitative results, some participant comments about this last item are included here. When they were asked to specifically report which learning strategies they have used, students found it difficult or did not express it in a concrete way, thus answering vaguely, such as "metacognition", or "none", in most cases. However, a few students reported more specifically:

'Asking questions to oneself' (Q4)

'Having breaks when studying: now I no longer study in periods of more than 45 minutes" (Q5)

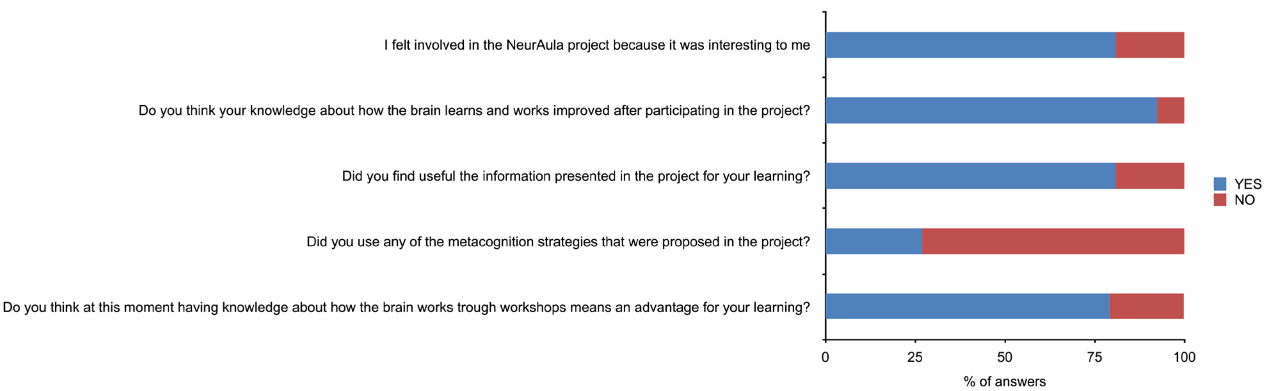

Figure 1. Assessment of the *NeurAula* program by students. Data were collected using the post-course ad hoc questionnaire (N = 26).

The participant comments in the blog site, which were collected from groups of 4-6 students, were analyzed together with the reports of single participants collected in the ad hoc post-course questionnaire. The aim of analyzing these comments is to support previous results, and to more finely dissect the student perceptions and involvement in the intervention.

Table 3 shows a general categorization of the comments provided by the participants, which includes some relevant quotes illustrating each category. As stated, students were satisfied in general with the methodology and contents delivered in the intervention. Further, students consistently gave positive feedback about their general interest in the program. In addition to the quotes included in **Table 3**, students also commented that they found the intervention to be interesting, when they were asked to justify their involvement. In one case, a student highlighted the positive environment of the general involvement of the class in the intervention, as the following quote states:

> 'There was a general commitment [of the class] to the [intervention]. (Q6)

When assessing specific sessions, students expressed a general interest in all of them. Reports revealed a positive impression of each session and the intervention as a whole. For example, a group of students commented that they were very interested in the contents of the four talks with supporting arguments, as shown in the following quotes:

> 'The talks were very interesting, because we think that the knowledge about the function of the brain and neurons are critical for understanding how the body works.' (B20)

> 'The topics in the talks were of a great educational interest'. (B21)

Regarding the methodology, student reports highlighted the dynamic approach of the whole program across all the feedback collected. Students also commented on the value of having experts involved in some sessions. They referred to either the quality and approach in which the experts gave their sessions, or to approachable personality of the experts (**Table 3**).

The contents about brain structure and function, and about the generalities of biological substrate for learning, were highlighted in several students' comments. Even though only few comments directly referred to specifically being motivated, the general comments show that the intervention positively impacted student motivation. According to the comments, the methodology, contents, and/or experts contributed to motivating the students. In some answers, the students even stated that they would like to repeat the program or see its further development (five comments).

Students highlighted the usefulness of content and learning strategies provided during the program and reported that it would be useful for their learning or their lives. In one case, a student stated the following:

> 'I think in some moment of my student life I could use some contents of this project and ways of studying. I very much liked it.' (I4)

In the post-course ad hoc questionnaire, we included an open-ended question to collect the comments of the participants about the strengths of the program, as well as about aspects to be improved. While some participants thought there was 'nothing to improve', others suggested bringing in more experts, provide more learning strategies, and expanding the program, among other comments.

Finally, the students assessed their satisfaction after having participated in the project. The average score from the experimental group participants in the post-course questionnaire was 7.15 (of a range from 0 to 10). Eighteen of the 26 respondents gave scores of 7 or 8 (see **Figure 2** for the distribution).

Long-term impact of NeurAula program

At 10 months after the intervention, we asked the participants to respond to a follow-up questionnaire about the learning strategies that appeared in NeurAula program and that they were currently using (**Figure 3**). Of note, 79% of the students stated that having participated in NeurAula program gave them an advantage for their learning process, even 10 months after the intervention (**Figure 1**). We asked them to provide comments justifying in which way their participation in the program gave them an advantage for learning. Their comments were positive

Table 3. Qualitative analysis of the intervention.

Categories	Sub-categories	Findings	Quotes
Interest	Methodology	Students positively valued the general dynamic and participative approach of the intervention.	B1. The expert in metacognition sessions made us participate and perform dynamic activities. B2. The debate was amusing and dynamic. B3. The poster session was an interesting and dynamic activity. B4 The 'mood' influences how fast you acquire knowledge.
	Contents in learning and neuroscience	Students reported interest in learning about the brain, emotions in learning, or positive valued in general the intervention.	B5. All the talks were interesting and fruitful. B6. [The talks] had positive value because they introduced us to neuroscience and professional world. Q1. It was very interesting to know how my brain works in learning. F1: Thanks to the project I am more conscious about how my brain works and I get maximal performance. F2: I think that for using the brain it is very important to know how it works.
	Experts	Students value closeness and warmth of some experts as well as their sessions.	B7. [The expert] was close to us. B8. [The expert] is a great professional and a great person. B9. We are very happy with the talks that we had the opportunity to attend. I1: The talks were very interesting.
Usefulness	Significance	A few comments described that it is applicable or related to life.	B10. We think the debate was a quite interesting activity, with cases that can be found in real life. B11. We consider that this knowledge can be applicable to both our student life and daily life.
	Learning strategies	Students considered the presentation of strategies useful for learning and their applicability.	B12. Learning about metacognition helps you to motivate for studying. B13: [Metacognition workshops] provided new very useful techniques for studying to be more effective and get better results. B14. Thanks to metacognition, we can go further and ask the things to ourselves. B15. We didn't learn too much from the debate, but what we learned is the opinions of others. I2: We learned new methods for learning. F3: Makes the learning process more amusing and more effective and optimizes time.
Motivation	-	Students reported knowledge about the brain and the dynamic approach generally awaked their curiosity and motivation.	Q2. All talks and sessions were interesting to me and awakened my curiosity. B16. [Metacognition workshops] give us more motivation to face new challenges and studies. B17. In general, everyone in the class was motivated and participative in the [poster session] activity. B18. The talks awoke our interest and curiosity. I3: I liked the talks about learning and metacognition. It made you stay more committed to the project.
Dissatisfaction	-	Some students reported that it did not contribute to their learning process, that they did not like the intervention, or that there is room for improvement.	Q3. It didn't seem too interesting to me, actually. B19. There are people who didn't like [the metacognition workshops] because this is useful for people who don't know how to study, but not for those who are well-organized.

in 22 cases, rather neutral in one case, and negative in 6 cases. Positive comments regarding their increased awareness about brain functions included the following answers:

> 'Thanks to the talks, I am more conscious of how the brain works, and I get maximal performance' (F1)

> 'The brain is social and is always learning' (F2)

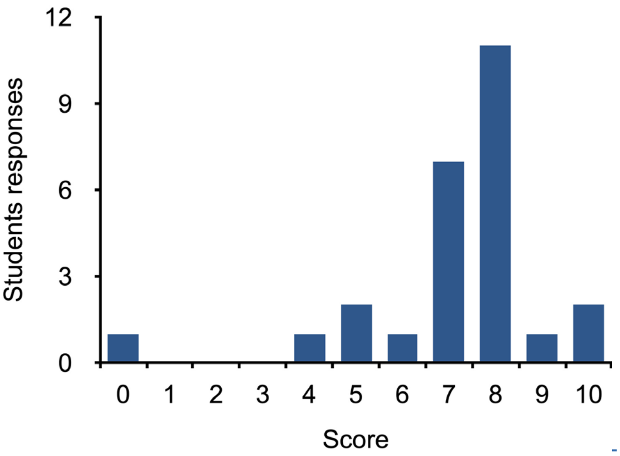

Figure 2. General satisfaction assessment by students of the *NeurAula* program, scoring 0 to 10 (*N* = 26).

> 'Allows you to deepen a topic that is usually not too known' (F3)

Comments regarding the usefulness of the contents for them included:

> 'I think it makes learning time more amusing and more effective and optimizes time' (F4)

> 'Knowing about the brain helps us to make good decisions' (F5)

Negative comments included:

> 'I don't know how my brain works' (F6)

> 'I don't remember anything from the project' (F7)

Discussion

Twenty-nine students completed the *NeurAula* program. The results presented here describe that the intervention generated an overall positive impact on the students. The students assessed the intervention with a score of 7.15 out of 10, whereby most students gave scores from 7 to 10. Importantly, the student comments also revealed that they felt the

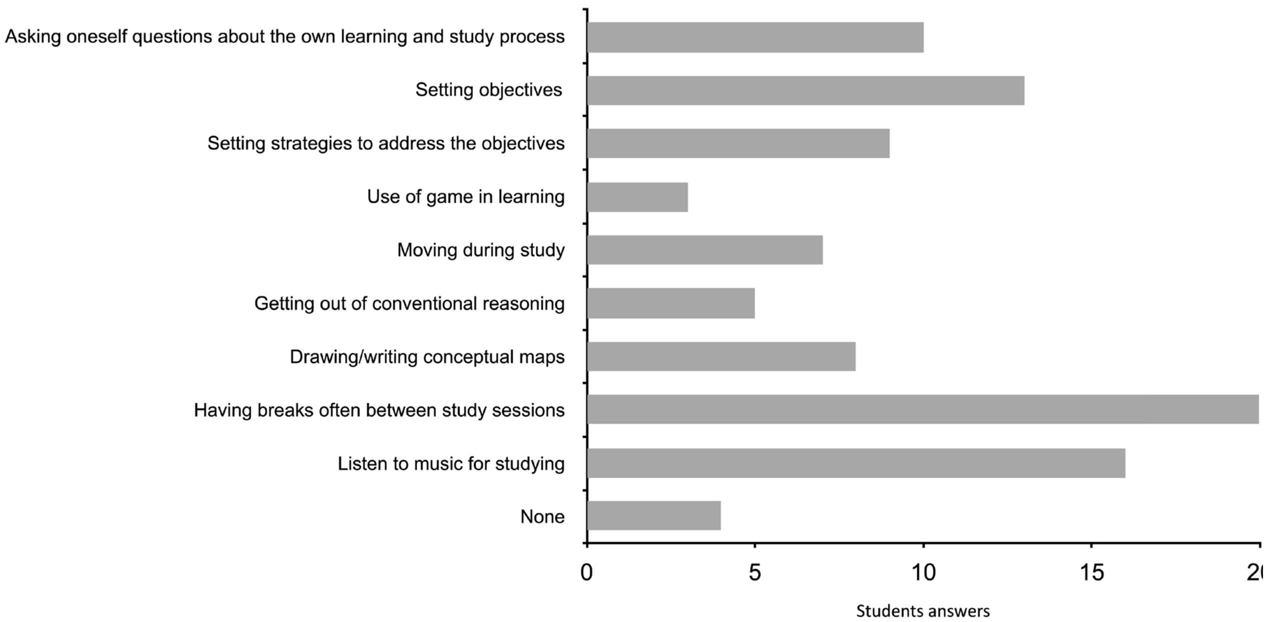

Figure 3. Use of learning strategies presented in the intervention at 10 months after follow-up. Twenty-nine students answered the questionnaire. Students could report the use of any of the described strategies.

intervention had an impact on their internal motivation for acquiring new knowledge, on the nature of their learning, and on their awareness of the learning process and of using metacognitive and other learning strategies. Numerous comments provided by students during the development of the program also highlighted their enthusiasm and positive attitude towards it, both during and after the intervention. This enthusiasm can be related to the novelty of knowledge provided in the intervention, as well as to innovative learning methodologies that were combined with traditional master-class methods given by experts, as students comments show.

Even though a clear acceptance and interest was self-reported by most students, the CMEA-55 instrument analysis did not reveal an impact on any of the nine variables assessed. Nevertheless, the results of the qualitative analysis of student opinions and comments show a clearly positive effect. They suggest that acquiring new knowledge about how learning occurs in the brain aroused their curiosity for neuroscience and promoted their intrinsic motivation to participate in the *NeurAula* project. Considering that the project was extracurricular, the fact that most students completed it can already be considered an indicator of intrinsic motivation. Some comments also showed that students found the program to be useful for improving their learning strategies. They also valued the teaching methodologies used, highlighting participatory debates and talks with neuroscientists. Students valued a course in which experts bring in their expertise and show real models of research careers. This directly challenges the usual educational paradigm, in which a single practitioner drives the class in learning situations. Interestingly, the value that students attributed to the task was increased after their participation in the program, a fact that has is highlighted when looking in detail at the items in each variable. After participating in the program, students valued how interesting, useful, and important they judged the tasks to be that they are doing in their classes[30], which had the objective of raising self-awareness. Similar interventions based on neuroscience workshops also positively impacted student beliefs and classroom motivation in primary school children[12], although other studies showed an impact on beliefs but not in motivation[5]. An online neuroscience-based intervention in a degree in computer science of several universities led to gains in a growth mindset and raised value as well as fostered career interest[32]. Interestingly, a reason for the lack of impact in this kind of interventions may rely on the context, where for example peer norms are supportive of the treatment message[33]. Indeed, mindset interventions generate controversy. For example, a recent meta-analysis revealed that nearly half of student mindset interventions that measured mindset before and after specific interventions failed to generate a shift[34]. Some of the controversies about mindset interventions are focused on some lines of evidence showing that trust in the instructor is much more relevant than students' views of their own intelligence (mindset) in measuring student commitment to, and engagement in active learning[35], and/or on the ability to persuade participants to shift their mindset[36]; that these interventions may not have a lasting impact on the mindset of participants[37]; that mindset may also affect a variety of other non-cognitive factors, such as the types of goals students set[38], how and to what they attribute their successes and struggles and how they cope with the challenges they encounter[39], and that students' mindsets are themselves malleable and appear to change over time[36]. This may explain at some extent why the study didn't achieve to show a significant change in the use of learning strategies as a result of the intervention. Undoubtedly, motivation is postulated to play a key role in self-regulated learning, which is directly related to achievement[40,41]. In contrast, about 20% of students did not feel motivated by the program itself, which may be explained by many reasons inside and outside the educational context that are outside the aim of this study.

A main objective of the intervention was to give students the possibility to self-reflect in a learning context, and to be more conscious about their own biological substrate as learners. Our results support that the intervention achieved the goal of offering a space to specifically self-reflect in that context. Despite not having any direct measures about self-concept through a specific validated instrument, student answers and comments indicated that they generally found a way to explore the learning process. They reported in many cases that they were conscious about the neurobiological basis of learning as well as about the usefulness of learning strategies that were worked on in the intervention. In another approach oriented to teachers and students, both groups reported that experiences with neuroscience were valuable for learning[42]. Additionally, knowledge about the neurobiology of learning could be connected to science education research to promote learning with innovative teaching[43]. It is worth mentioning that the average high profile of the students that participated in the program could determine the success of the intervention, as values in the CMEA-55 were above 5 out of 7 in 5 out of 9 variables in the pre-test. Of note, we cannot rule out that the background of the participants, who were biomedical vocational education students, may also have played a role in how students integrated this kind of content into their learning strategies.

When looking at the impact the program had on the learning strategies students use, a result in the 10-month follow-up questionnaire revealed that the experimental group of student were actually using some of the strategies that were presented in the project. Twenty-five of 29 participants (86.2%) reported they used one or more learning strategies from those shown in **Figure 1**. The most widely used strategies were spaced learning and listening to music while studying, a strategy that has been shown to promote attention[44], reduce levels of cortisol associated with stress[45,46], and increase the release of dopamine[47], a feel-good neurotransmitter involved in the brain reward system that has a critical role in learning (for a review, see[48]). However, the current research design cannot detect a significant change in the use of strategies. Of note, while we cannot rule out the students had already used these strategies before, the intervention could still make them conscious that they were actually using them, and especially those that are less evident, such as the general metacognitive strategies of asking oneself questions, setting goals, and so on. The use of this type of strategy is clearly related to high achievers[27,28]. Thus, we believe that practicing and mastering these techniques—starting with the presentation of their existence and making some students aware they use them—is critical for students' success in their educational centers as well as for lifelong learning. Another interesting insight from these results is that some students reported the use of creative thinking, or out-of-conventional reasoning. This may indicate that some students feel confident to relate the value of creativity to their own learning process.

Conclusions

The majority of students who participated considered the intervention based on the neuroscience of learning to be useful for their learning, and that it generated their curiosity for deepening the nature of learning. Students valued discussions with experts as well as the participatory activities. Some students considered that the strategies for learning will help them to be more efficient, and some used them after the program. However, it was not possible to show evidence of a significant change in the use of learning strategies as a result of the intervention. Future research will be critical to support the idea that similar interventions may be used in different learning contexts, such as secondary or higher education, with the aim of providing tools to students for helping them to become more effective learners.

Limitations

Our study had a few limitations. For instance, using a larger sample would have likely resulted in more consistent results in the CMEA-55 analysis. Additionally, the lack of effect could be due to the short time of the post-course assessment, which was given at one week. Undoubtedly, students would benefit from long-term practice and activities related to the program, a fact that may impact their motivation and the use of strategies for learning. Further, we cannot rule out the possibility that students already used the learning strategies in the program prior to the intervention. And finally, we could not relate the impact of the intervention to the final academic results. This is due on one hand to technical difficulties, and on the other hand to the difficulty of specifically relating success to the intervention for the multiple contingencies during the academic course.

Ethical considerations

The Ethic Committee of Pompeu Fabra University reviewed the procedure. The Fundació BCN Formació Professional and the management team of Escola Pia Nostra Senyora approved the study. All participants were informed of the project's objectives and methods; participation was voluntary and anonymous; and deciding whether to participate in the data collection had no consequences for students. Students were informed of the characteristics of the study, gave their oral consent to participate, and agreed to fulfill study requirements. The participating students gave written informed consent.

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The school management team approved the realization of the study. All participants were informed of the project's objectives and methods; participation was voluntary and anonymous; and deciding whether to participate in the data collection had no consequences. Students were informed of the characteristics of the study, gave their oral consent to participate, and agreed to fulfill study requirements. The students also signed written informed consents.

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Supplementary Table 1. CMEA-55 QUESTIONNAIRE AND CORRESPONDENCE TO CMEA-810

CMEA-55 MOTIVATION SCALE VARIABLES (MOTIVACIÓN)
Orientación metas extrínsecas (1, 16, 22, 24)
Orientación metas intrínsecas (7, 11, 13, 30)
Valor de la tarea (4, 10, 17, 23, 26, 27)
Creencias control (2,9, 18, 25)
Autoeficacia para el aprendizaje (5, 6, 12, 15, 20, 21, 29, 31)
Ansiedad ante los exámenes (3, 8, 14, 19, 28)
CMEA-55 LEARNING STRATEGIES SCALE VARIABLES (ESTRATEGIAS DE APRENDIZAJE)
Autoregulación metacognitiva (32 *, 34, 36, 38, 41, 42, 43, 44 *, 46, 51, 53, 54)
Administración del tiempo y del espacio (33, 37, 40 *, 47, 48, 49, 52, 55 *)
Regulación del esfuerzo (35 *, 39, 45 *, 50)
ITEMS IN MOTIVATION SCALE VARIABLES
1. En una clase como esta prefiero que el material de la asignatura sea realmente desafiante para aprender cosas nuevas.
2. Si estudio de manera apropiada, podré aprender el contenido de este curso.
3. Cuando presento un examen, pienso en lo mal que lo estoy haciendo comparado con mis compañeros.
4. Pienso que podré utilizar lo que aprenda en esta clase, en otras asignaturas.
5. Creo que obtendré una excelente calificación en esta clase.
6. Tengo la certeza de que puedo entender el contenido más difícil presentado en las lecturas de este curso.
7. Obtener una buena calificación en esta clase es la cosa más satisfactoria para mí en este momento.
8. Mientras presento un examen, pienso en las preguntas que he dejado sin contestar.
9. Es culpa mía si no aprendo el contenido de este curso.
10. Es importante para mí aprender el contenido de esta clase.
11. Mi principal preocupación en esta clase es obtener una buena calificación para mejorar mi promedio.
12. Confío en que puedo aprender los conceptos básicos que me enseñen en esta clase.
13. Si puedo, quiero obtener mejores calificaciones en esta clase que la mayoría de mis compañeros.
14. Cuando presento un examen pienso en las consecuencias de fallar.
15. Confío en que puedo entender lo más complicado que me explique el profesor en este curso.
16. En una clase como esta, prefiero materiales que despierten mi curiosidad, aunque sean difíciles de aprender.
17. Estoy muy interesado en el contenido de este curso.
18. Si lo intento de verdad, comprenderé los contenidos del curso.
19. Tengo sentimientos de inseguridad y ansiedad cuando presento un examen.
20. Confío en que puedo hacer un excelente trabajo en las tareas y exámenes de este curso.
21. Espero hacerlo bien en esta clase.
22. Lo más satisfactorio para mí en esta asignatura es tratar de entender el contenido tan a fondo como sea posible.
23. Creo que me es útil aprender el contenido de esta clase.
24. Cuando tenga la oportunidad en este curso, elegiré tareas o actividades que me permitan aprender cosas nuevas aunque no me garanticen buenas calificaciones.

25. Si no entiendo el contenido del curso, es porque no me esfuerzo lo suficiente.
26. Me gusta el tema de este curso.
27. Entender el tema principal de esta clase es muy importante para mí.
28. Siento mi corazón latir fuertemente cuando presento un examen.
29. Estoy seguro que puedo dominar las habilidades que enseñan en esta clase.
30. Quiero hacerlo bien en esta clase porque es importante para mí demostrar mi habilidad a mi familia, amigos, compañeros y empleadores.
31. Teniendo en cuenta la dificultad de este curso, el profesor y mis habilidades, pienso que lo haré bien en esta clase.
ITEMS IN THE LEARNING STRATEGIES SCALE (correspondence to CMEA-81 in brackets)
32 (33). Durante la clase, a menudo pierdo aspectos importantes porque estoy pensando en otras cosas.
33 (35). Por lo general estudio en un lugar donde pueda concentrarme en mi tarea.
34 (36). Cuando estudio para este curso, me hago preguntas para ayudarme a enfocar mi lectura.
35 (37). Muchas veces me siento tan perezoso o aburrido cuando estudio para esta clase que dejo antes de terminar lo que planeé hacer.
36 (41). Cuando estoy haciendo una lectura, y me "pierdo" al leer vuelvo para atrás e intento aclararlo.
37 (43). Hago buen uso de mi tiempo de estudio para este curso.
38 (44). Si las lecturas del curso son difíciles de entender, cambio mi manera de leerlos.
39 (48). Trabajo fuerte para hacerlo bien en esta clase aunque no me guste lo que estoy haciendo en ese momento.
40 (52). Me resulta difícil seguir un horario de estudio.
41 (54). Antes de estudiar un material nuevo para el curso, lo leo de manera rápida para ver como está organizado.
42 (55). Mientras estudio para esta clase, me hago preguntas para asegurarme que entiendo el material que he leído.
43 (56). Trato de cambiar mi manera de estudiar para encajar mejor con la asignatura y la manera de enseñarla del profesor.
44 (57). Muchas veces me doy cuenta de que he estado leyendo para esta clase pero no se de que iba la lectura.
45 (60). Cuando lo que tengo que hacer para esta clase es difícil, o no lo hago o sólo estudio lo fácil.
46 (61). Cuando estudio un material, intento pensar en lo que tengo que aprender de él, antes de ponerme a leerlo.
47 (61). Tengo un lugar específico para estudiar.
48 (70). Me aseguro de estar al día con las lecturas y trabajos de este curso.
49 (73). Asisto con regularidad a esta clase.
50 (74). Incluso cuando los materiales de la clase son aburridos o poco interesantes, sigo trabajando hasta terminarlos.
51 (76). Cuando estudio para este curso trato de identificar que conceptos no entiendo bien.
52 (77). A menudo encuentro que no le dedico mucho tiempo a este curso a causa de otras actividades.
53 (78). Cuando estudio para esta clase, establezco mis propias metas para dirigir mis actividades en cada período de estudio.
54 (79). Si tomo notas de clase confusas, me aseguro de organizarlas más tarde.
55 (80). Pocas veces encuentro tiempo para revisar mis notas o lecturas antes de un examen.