

Scientific Studying and the Effects of Physical Exercise on Cognitive Capacities

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Abstract

Scientific Studying is a studying methodology based on the scientific experiment, which holds that only through self-experimentation can one determine his/her optimal way to study. We conducted a series of experiments with middle and high-school students, who studied for given periods of time using different study methodologies, and we quantified their results in terms of increase in learning power. We found that a methodology that includes subdividing the time allotted to the study activity in intervals and alternating the subject matters being studied led to an increase in learning power of fifty percent in only a few months. Furthermore, we found that the smaller the interval, such as 20-minutes or less, the better the increase in learning power. Crucially, when the intervals of study activity alternate with intervals where an aerobic physical activity is being performed, the increase in learning power is significant. We link our findings with studies that show the effects of high-intensity interval activity on attention and concentration in the classroom and generally, with the positive effects of performing a physical activity on brain function. Scientific Studying has the potential to yield enormous beneficial results for our society by increasing the level of education around the world.

1. Introduction

We have proposed in [1] and [2] to substitute the non-scientific 'traditional' study methodologies used by students all over the world with Scientific Studying, a scientific methodology consisting in a series of self-designed and self-administered scientific experiments, with the result of considerably improving learning power. We have furthermore shown in [3] how the learning power obtained through the application of Scientific Studying is proportionate to the level of difficulty of the subject matter being studied. Thus, the application of Scientific Studying may lead to improved competency levels in any given subject that proves difficult for a given student, often in Mathematics, perceived as one of the most difficult subject in schools.

In this paper we investigate the link between Scientific Studying and the effects of physical activity on brain function. One of the study

methodologies we have found most productive is the subdivision of the time allotted to the study activity in intervals. When the study activity interval alternates with a break interval that includes a physical activity, a considerable increase in learning power is obtained. We investigate these results in view of studies showing the effects of physical activity on brain function. For instance, performing twenty-minute treadmill sessions has been shown to improve preadolescent cognitive control of attention and school-based academic performance [4]. Our research into optimal study methodologies has far reaching consequences and the potential to significantly contribute to the improvement of the level of education around the world.

2. The principles of Scientific Studying

Scientific Studying is based on the following assumptions:

- i) There is a significant level of waste in the learning activity of students all over the world. By "waste" we mean that students generally study using a suboptimal methodology, which we have defined 'Traditional Studying', and which is often the result of a number of inputs learned unconsciously and applied mechanically since early childhood. Through personal observation, a student often emulates the way an older sibling or a classmate studies. It is extremely rare that a student without exposure to Scientific Studying would consciously plan for a number of different scientific experiments and diligently execute and document them in order to maximize his or her learning power.
- ii) A scientific method can be successfully used to solve this waste. By "scientific method," we mean a method that satisfies the requirements of being unbiased, conscious, measured and documented, and communicated.

Thus, the centrepiece of Scientific Studying is the scientific experiment. In order to be scientific, the experiment has to satisfy certain specific requirements, namely be unbiased, be conscious, be measured and documented, and be communicated. This stands radically opposed to the Traditional Studying methods employed – almost automatically – by students around the world. Table 1 resumes the main differences between Scientific Studying and Traditional Studying.

Table 1. Comparison between Scientific Studying and Traditional Studying

	Traditional Studying	Scientific Studying
Goal	Study (the way we are used to, the way we feel, the way we naturally do, etc.)	Study (using an optimal methodology)
Methodology	Acquired through a number of inputs learned almost unconsciously during several years, since early childhood	Acquired in a relatively short period of time (typically a few months to one year) through a number of scientific experiments conducted by the student himself/herself (with or without the help of an instructor) on methods, parameters, and implements, starting with a methodology that proved optimal for a majority of subjects in previous experiments
Characteristics	<ul style="list-style-type: none"> • Mostly unconscious and unplanned • Mostly unaware of the existence of waste and entropy • No conscious self-observation 	<ul style="list-style-type: none"> • Strictly conscious and planned • Conscious goal of reducing or eliminating waste and entropy • Conscious goal of maximizing the learning power • Conscious self observation
Prerequisites	<ul style="list-style-type: none"> • None: the student is not formally exposed to "learn how to learn in a scientific context" 	<ul style="list-style-type: none"> • Formal exposure to "learn how to learn in a scientific context"
Separation of planning and execution of work/study	<ul style="list-style-type: none"> • No: they are randomly mixed together 	<ul style="list-style-type: none"> • Yes: the student plans first and executes later
Measurements and communication of results	<ul style="list-style-type: none"> • None: there are only individual isolated study methods 	<ul style="list-style-type: none"> • Formal measurements and communication of results, in view of further developing them

Our proposal has essentially been to shift study methodologies from nonscientific to scientific, aiming to reach impressive productivity improvements, which can in turn revolutionize education. Crucially, Scientific Studying is not about a particular methodology in and of itself, but rather about the importance of being open to scientific experimentation and allowing oneself to scientifically experiment with different methodologies in order to find the winning one. Thus, students perform a series of experiments, using methods, parameters and implements and measure the effect on the learning power before proceeding to new experiments with modified methods, parameters and implements. While these experiments can be continued indefinitely, it is usually the case that one reaches a winning methodology that yields significantly improved results after a few rounds of experiments.

The tool kit of Scientific Studying contains:

i) Methods: One example of method is the separation of the time dedicated to study into study activity and recreational activity. Time management is a crucial element in the implementation of Scientific Studying. While the natural tendency is to mix the time dedicated to study and the time dedicated to recreation, this leads to an important loss in productivity. The way to avoid this is to appropriately plan, in writing, for a specific time segment for study and a specific time segment for recreational activity. Such detailed planning can cover the day or simply a few hours.

Moreover, as an added experiment, subdividing time provides better learning power when used in conjunction with alternating the subject matters that are being studied. In the experiments we performed, time segments of fifteen or twenty minutes yielded

the best results. Thus, for instance, a student would study Literature for fifteen minutes, followed by History for fifteen minutes, Math for fifteen minutes, then take a fifteen minutes pause, before continuing with another round of study segments. This typically contributes, according to our results, to the efficiency and effectiveness of the study activity. A shorter time frame allotted per subject matter renders the study more focused. This is easily understandable considering that the smaller the time segment, the smaller the time wasted: in a small time segment, even a minimal waste of time will have a relative large ratio of wasted time on allocated time. For instance, five minutes' waste on a two-hour interval (120 minutes) is $5/120=4.2$ or 4.2% of the overall time. However, five minutes of wasted time on a total of twenty minutes is $5/20=0.25$ or 25% of the overall time, thus much larger percentage-wise and therefore more visible and easier to detect and control. This is in sharp contrast to Traditional Studying, which typically consists of studying one subject matter for a prolonged period of time.

ii) Parameters: The parameters are, for instance, in the case of the subject matter alternation method, the length of the study intervals, as well as the length of the recreational activity.

iii) Implements: The implements are, for instance, a music player (studying with or without the music), markers (underlining or not important concepts, etc.), pens or pencils, and so on.

The study methodology is the sum of the methods, parameters, and implements used at a given time. The optimal methodology, which is in essence the outcome of Scientific Studying, is the combination of several methods, parameters, and implements that yield the maximum learning power to the specific student.

3. Experiments

3.1. Design

We conducted four sets of experiments with middle and high school students over a period of eight months. Participants were given a number of methods, parameters and implements as potential study methodologies and were encouraged to customize and change them at will. Table 2 outlines some of the methodologies we first proposed to the participants.

Table 2. Methods, parameters, and implements proposed to participants in the four sets of experiments

Experiments	Methods	Parameters	Implements
First Round	Clear division of study time and recreational time Subject matter alternation	Length of study time and length of recreational time Frequency of subject matter alternation	Paper on which the list of subject matters is written and where the detailed plan is also written (highly visible to the student) Watch (highly visible to the student and close to the study plan)
Second Round	Introduction in the study plan of intervals to review or repeat aloud what was studied in the previous segments	Frequency and length of time segments	Paper on which the list of subject matters is written and where the detailed plan is also written (highly visible to the student) Watch (highly visible to the student and close to the study plan)
Third Round	Listening or not listening to music while studying	Type of music (classical, instrumental, etc.)	Radio or CD player or iPod, etc.
Fourth Round	Underlining or not underlining key concepts	The number of different colors or intensity in the underlining	Pencils, different colored pens, highlighters, markers, etc.
Fifth Round	Writing or not writing key concepts in the books being studied, with or without a hierarchical sequence	The number of the different hierarchical levels	Pencils, pens, etc.

For instance, using two methods (i. subdivision of the time allocated to study into study time and recreational time, and ii. alternation of subject matters within the time allocated to study), the students prepared a customised study plan. For example, if a student had availability to study from 14:00 to 19:30, here is a study plan that would be drafted by the student before starting to study and then strictly followed:

Subject Matters to Study:

- Mathematics
- Physics
- History

Study Plan:

Mathematics:	14:00–14:20
History:	14:20–14:40
Physics:	14:40–15:00
Recreation Time: 15:00–15:20	
Mathematics:	15:20–15:40
History:	15:40–16:00
Physics:	16:00–16:20
Recreation Time: 16:20–16:40	
Mathematics:	16:40–17:00
History:	17:00–17:20
Physics:	17:20–17:40
Review ¹⁷ Mathematics:	17:40–17:55
Review History:	17:55–19:10
Review Physics:	19:10–19:25

Participants’ marks were recorded before the experiments and after each application of a given methodology. We measured the increase in learning power based on two factors: marks and average time dedicated to the study activity, or more specifically:

i) Average marks before the experiments, as compared to average marks after the experiments, calculated both by subject matter and by overall average. The increase or decrease in average mark was calculated through a weighting process taking into consideration the overall mark distribution in the school. For example, a 100% improvement (in terms of marks only) was obtained if the student improved from the lowest score of all the students in the school to the highest. Since all this was subject to a weighting process, the higher the density of marks in the segment representing the absolute increase, the higher the percentage increase as compared to the absolute increase.

ii) Average number of hours dedicated to study before the experiments, as compared to average number of hours dedicated to study after the experiments.

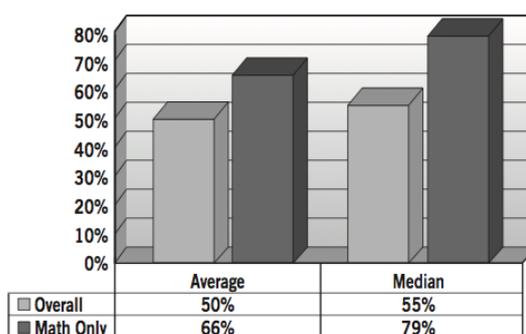
By using both measures i and ii outlined above, we calculated an index that quantifies the percentage increase in learning power, which is directly proportional to i above and inversely proportional to ii above.

3.2. General results

The results have been strong across the entire spectrum of experiments. We illustrate in Table 3 below the results of the first three sets of experiments, while the full results are detailed in [1].

Fourteen students participated in the first three sets of experiments. Eleven students completed the experiments and three dropped out. All the students who completed the experiments achieved impressive improvements of overall learning power, from a minimum of 23% to a maximum of 79%, with an average of 50% and a median of 55%.

Table 3. Improvements in learning power (recreational time included) for the first three sets of experiments



We emphasise also the results in Math, which was the subject matter that achieved the highest increase in learning power. For eight of the eleven students the improvement in learning power was larger than the overall improvement, ranging from a minimum of 24% to a maximum of 109%, with an average of 66% and a median of 79%. While the discussion of these results is detailed in [3], our results allow us to conclude that the application of Scientific Studying leads to significant increases in learning power, particularly in the subject matter perceived as most difficult for each subject. We'll turn next to the results of the students that alternated study activity intervals with physical activity breaks.

4. Effects of physical activity

4.1. Our experiments and results

We have outlined above in Table 2 some of the study methodologies we proposed to the participants in our experiments. As a related additional methodology, in the fourth set of experiments, a limited number of students were encouraged to work out during the recreational breaks. The proposed workout was, in this case, an aerobics workout. We executed the same rounds of methods, parameters and implements as in the other three sets of experiments, i.e. mainly subdivision of time and subject matter alternation, with the only difference being that, for the subjects that so chose, the time allotted for recreational breaks was used for working out. Two out of 23 students, student 18 (S18), and student 23 (S23) chose to experiment with this methodology. We illustrate in Table 4 the general results of the fourth set of experiments, and in Table 5 the highest increases in average marks per student.

Table 4. Improvements in learning power (recreational time included) for the fourth set of experiments

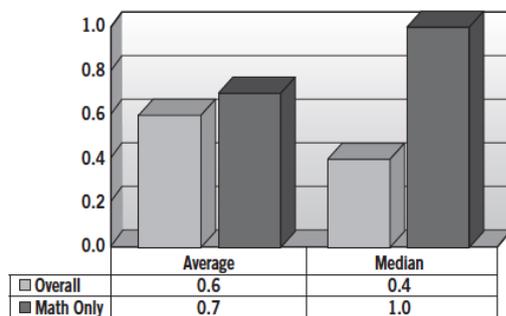
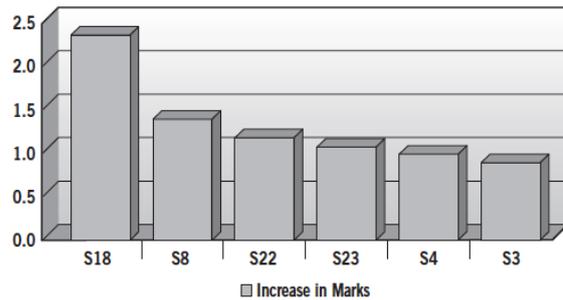


Table 5. Highest increases in average marks per student in the fourth set of experiments



These results indicate that S18 had the largest increase in learning power in this group, with average marks improving by 2.2 from 5.3 to 7.5 (the maximal grade in this institution being 10). Note that this is almost double the increase in learning power obtained by the next best result (namely, S8, who improved his grades by 1.3, from 4.3 to 5.7, but who opted out of the physical exercise during break option).

S18's study plan, illustrated below, includes time segments where each change in subject matter is preceded by a recreational period. Interestingly, the student alternated between short recreational periods with no workout, and longer recreational periods with time for working out. He noted that he likes making frequent 30-minutes workout breaks because "one studies better after a workout". This example of a study plan also proves how the student can customize the study plan, vary the parameters, test the results, in other words, how the student can experiment with different study methodologies in order to achieve a customized self-designed study methodology that yields the highest increase in learning power.

S18's study plan:
 study 25 min
 break 5 min
 study 25 min
 break 30 min (with physical workout)
 study 25 min
 break 5 min
 study 25 min
 break 30 min (with physical workout)

Student (S23) chose to study in longer intervals, with short breaks and a unique workout break in the middle of the time allotted to study, as illustrated below. S23 obtained a less impressive increase in learning power than S18, his average marks improved by 0.6 from 6.0 to 6.6. However, his performance was still above the median 0.4 increase and in line with the average increase in learning power.

S23's study plan:

study 45 min

break 5 min

study 45 min

break 60 min (with physical workout)

study 45 min

break 5 min

study 45 min

Even though the sample of this experiment is small, the results of the students involved show that it is possible to make a connection between working out during certain recreational segments and an increase in study efficiency. This confirms previous findings in the field of neurocognitive kinesiology making a clear link between aerobic fitness and cognitive performance. Studies reveal that brain activity (as in a decision-making task) increases more rapidly following a time of intense physical activity such as running on a treadmill. As reported in [4], for instance, performing twenty-minute treadmill sessions improve preadolescent cognitive control of attention and school-based academic performance.

4.2. Previous findings

“An emerging body of multidisciplinary literature has documented the beneficial influence of physical activity engendered through aerobic exercise on selective aspects of brain function.” [5] The authors associate the effects of aerobic exercise in childhood with enhanced cortical development, i.e. development of the cerebral cortex that is involved in higher order processing such as information processing and language. In other words, researchers found that when measuring attention, working memory and processing speed, students that are more fit show more brain activity than the students that are not fit (particularly important seems to be the combination of aerobic fitness and a healthy body mass index).

The results of these studies are (slowly) finding their way in curriculum design in schools, through the creation of academic programs that include enhanced physical education (PE) alongside ‘core’ subject matters such as Math and Science. For instance, the “*Physical Activity Across the Curriculum*” (PAAC) program was developed in elementary schools, where classroom teachers were trained to deliver academic instruction using physical activity [6]. Furthermore, [7] discusses how schools such as the Naperville Central High School in the Chicago area adopted a new type of PE classes, strategically scheduled before subjects such as Math or English, where students are monitored to achieve a maximum high heart rate of 145-185 bpm. The assumption is that this aerobic activity ‘sparks biological changes that encourage brain cells to bind

one another” [11], thus entering the class with ‘heightened awareness’. While the original motivation was to fight child obesity, the impact of these ‘new’ PE classes on academic performance became quickly evident. Naperville students now rank high in international tests in Math and Science.

4.3. Discussion

On the background of these studies, the results of our experiments in the optimization of the study activity bring further support to the powerful idea that physical exercise has a clear impact on academic performance. The Scientific Studying methodology that we are proposing easily and naturally integrates what we know about brain function and the results of previous studies in two ways:

i) As we noted before, we propose that a fundamental step towards achieving an optimal studying and learning efficiency is to alternate the study activity intervals with physical activity breaks. Scientific Studying provides students with a basic study method that allows each student to include customized physical activity breaks in his/her study plan. These active breaks will have the effect of enhancing his/her brain activity and thus lead to an increased efficiency of the next study activity interval.

ii) The results of our experiments also indicate that shorter intervals (for both the study activity and the break) work better than longer intervals. As a matter of fact, the student that chose more frequent and shorter break intervals with workout (S18) obtained a higher increase in learning power than the student using just one long work brake interval with workout (S23).

The use of short rather than long study intervals is supported by studies showing that optimal classroom learning is associated with shorter instruction times. For instance, studies reported in [8] have shown that children in elementary school who are confined for prolonged periods often become more restless and experience reduced concentration [9]. Moreover, when children continue to work for long periods without receiving a recess break, fidgety behaviors increases by 6% and off-task behavior increases by 4% [10]. The authors conclude that children might think and work less efficiently when engaged in long periods of uninterrupted instructional time.

Subdividing time into smaller segments and alternating the study activity with aerobic workouts can be applied in and out of the classroom.

Within the classroom, this approach has been explored in programs such as ‘*TAKE 10!*’, which incorporates grade-specific activities linked to core curriculum objectives for mathematics, science, language arts, social studies, and character education in 10-minute segments [11]. Another example,

reported in [12], is a Saskatoon school where grade 8 students are using treadmills and stationary bicycles for 20-minute cycles as part of the class instruction.

We argue that through the application of Scientific Studying, this approach can be used outside of the classroom as well, namely in the individual study activity, as a customised methodology yielding a considerable increase in learning power.

5. Conclusion

In view of the massive support coming from multidisciplinary studies reporting the positive effects of physical activity on brain function, the results of the experiments we performed with a limited number of high-school students reveal the immense potential of including physical activity breaks in the course of the study activity. This is why adopting Scientific Studying may result in substantial increases in study efficiency. Adopting Scientific Studying implies, on the part of the student, a conscious elaboration of a study plan that includes periods of study activity and break periods, best if combined with performing an intense physical activity in given break periods.

Further experiments are needed in order to specifically determine the increase in learning power induced by physical activity. Additional experiments will also allow exploring the optimal length of the study intervals, the optimal length of the break intervals, as well as the optimal frequency of the workout interval. This is important because the generally most successful parameters should be the ones tried first by new students commencing their Scientific Studying experiments. On the basis of the experiments reported above, more frequent and shorter brake intervals with workout may be more effective to improve learning power than just one long brake interval with workout. Therefore in the next experiments to new students that intend to use Scientific Studying, frequent 30-minute brake intervals could be proposed as a first methodology, and then the students could modify the parameters (for instance, experiment with 20 minutes break intervals with workout, with 40 minutes intervals with workout, etc.), measure the results, and consequently, choose the parameters that work best for each individual. This, again, shows the power of the scientific experiment.

On a final note, while we have only discussed the time parameter above, there are other parameters to consider. For instance, the type of workout can be modified and tested (consider, for instance, aerobics, yoga, weight lifting, etc.). Different types of workout alternation can also be tested. For instance, a given study interval could be followed by an aerobics workout interval, while the subsequent study interval could be followed by a weight lifting workout

interval, and so on, the idea being that different mental activities may be enhanced by a particular type of physical activity. Studies reported in [7] show that among different types of physical activity, aerobics definitely has a positive impact on brain function. There is less evidence of a correlation with nonaerobic activities (such as yoga), but this is subject to further experimentation.

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