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Second teaching cycle

From theory to practice in research: and integrated approach to reinforce learning in research-based exercises

Introduction

Integrated methods combining the strengths of synchronous (face-to-face learning) and asynchronous (text-based learning) have received much attention during the last years, mostly due to the arrival of e-learning (Sotillo 2000, Garrison and Kanuka 2004) and distance-based learning methods (Chou 2002). Although not traditionally assigned to the last group, active reading by the student via reading lists or materials accessible online, followed by workshops where students have the opportunity to discuss with their peers and instructor the materials provided is part of such an integrated curriculum.

Research-based learning promotes motivation from expert enthusiastic lectures, active learning where students develop skills and knowledge by themselves, and learning of time and resource-management (Jenkins et al. 1998). However, students need to be introduced to an often slow process where the tools to do research are not clear from the beginning and need to be practised through successive iterations where teacher's guidance must be continuous and avoid excessive intervention (Kirschner et al. 2006).

Typically, the lack of knowledge on some topics by many undergraduate students calls for the need to reinforce concepts, often through repetition. Students leading towards reading relatively large amounts of course material often understand concepts and develop skills through successive practice to reinforce their reading and interest in some topic and improve responsiveness to instruction (Shaw 1999). Reinforcement learning (i.e., learning from the consequences of one's own actions, following a particular stimulus response, rather than explicit lecturing) has been traditionally put forward as a behaviourist approach to the theories of
effective learning. The main principles of the reinforcement learning cycle (seen in Fig.1), involve (1) the intermittent reinforcement of behaviour, (2) the presentation of information in small amounts, and (3) the use of “similar stimuli” in order to promote reinforcement (Skinner 1953). When the response is followed by a stimulus that increases the frequency of that behaviour, we might be introducing effective learning in the individual.

![Fig. 1. A behaviourist approach: The reinforcement learning cycle.](image)

Reinforcement learning in students is typically introduced through interactive activities. However, the model implicitly assumes a constant learning process as the number of successive stimuli grows. This assertion is partially reinforced by the best-know case of the forgetting curve (Ebbinghaus, 1913). It describes an exponentially decreasing curve in terms of what we tend to remember through time after a learning action, and it follow a simple equation 

\[
R = s \cdot e^{-\frac{t}{\tau}}
\]

where \(R\) is the memory, \(t\) stands for time elapsed since the last learning event, and \(s\) is the relative strength of memory, usually dependent on the individual capacity and previous training involved in memory. One of the various techniques suggested to reduce memory loss of one or several concepts involves repetition based on active recalls, where the interval between repetitions increases with successive repetitions to optimize the memory of an event, and the time of the each successive stimulus reduces (Fig. 2).
Fig. 2. Depicted example of the *forgetting curve* subject to repetition in an individual. The dotted line is the threshold of memory under which the teacher does not want to take the student. Every time the threshold is reached, a new repetition takes place. With more repetitions, memory gains strength in the individual, depicted by the successive curves with slower decay.

Repetition takes Skinner's reinforcement learning loop into practical considerations by application to the forgetting learning curve. However, effective learning is highly complemented to experienced learning through personal reading. Personal reading is optimized when the subject is learned and recalled from what the student already knows, that is, when there has been a prior experience on the topic in order to better establish links between concepts (*deep reading*) (Brown & Atkins 1988). In this context, a proper prior framework greatly activates the learning experience. A combination of *deep reading* and *directed reading* (that to acquire specific knowledge on theories) is supposed to maximize the learning experience.

Optimizing the learning experience though a combination of repetition, active reading, and student-experienced research-based learning should therefore benefit overall performance. Active reading and research, however, should compensate the need for further repetition of concepts by the teacher. Thus, in integrated teaching methods, the goal should be to minimize the iterations of intervention while maximizing the student's own experience of research.
Ebbinghaus' model, however, stresses behaviour at the level of the individual. In a population (i.e., a class of students), the exponential decay model should rather imply that, the longer the time elapsed, the more divergent are the trajectories of memory among individuals, given the individual nature of $s$, the relative strength of memory (Fig. 3). This divergence due to small initial differences was initially proposed by Nyquist (1928) and in the current case implies that, in order to optimize an overall good performance for all individuals, repetitions should actually be rather consecutive in time, avoiding divergent trajectories while optimizing the memory kept. Therefore, two main points are addressed in this manuscript: Is the repetition loop really necessary when combined with active reading and research by the student? If so, how many repetitive iterations does the student need in order to properly grasp and reflect on the concepts and theories intended to be learned and developed? If motivation for research balances the need for repetition, both the student and the teacher will greatly benefit from an integrated approach.

![Graph showing memory retention over time](image)

**Fig. 3.** The *forgetting curve* subject to repetition in an population. For clarity the population is composed of three individuals with different memory strengths (one central solid line and two dashed lines). As time elapses, variation in the optimal times for repetition increases. But with further repetitions variation also increases. This implies loss of correlation in the data, and hence potential for not finding significant patterns in population indicators of learning.
Learning Outcomes

1. To develop an understanding on the basic concepts and theories regarding resilience theory in ecological research.
2. To increase reflection on the student towards those concepts (often mathematically complex) and their interpretation.
3. To prepare the student, through the use of active reading and research-based approach towards an essay on resilience in ecological systems that will finally be assessed for the final mark.

Methods

In a class of 80 third-year undergraduate Biology students enrolled in a course on “Population and Community Ecology”, the teaching cycle was compounded by different interventions accounting for the Skinner's loop of repetition. The overall intervention (Fig. 4) was split in three parts:

I. In the first instance, students were given two lectures on resilience in ecological systems. In the first lecture, students were given a standard lecture on the basics of resilience in ecological systems. The lecture comprehended a series of case studies with explanations on basic mathematical approaches on the problem of resilience to give the student an introduction. In the second lecture, two days later, students were shown a video on a conference by Prof. Marten Scheffer, located in the Stockholm's Resilience Centre webpage on “Thresholds for Catastrophic Shifts” (http://www.stockholmresilience.org/seminarandevents/stockholmseminars/previousseminars/2007/ss2007/profmartenschefferontresholdsforcatastrophicshifts.5_aeea46911a312742798004509.html). The video intended to reinforce the student learning experience by further commenting several examples of resilience from a second and world-renowned expert in the subject. Some of these examples had been previously described in the initial lecture.

II. The second part was the Reinforcement Loop itself. After the last lecture, students were advised to come to two practical sessions - starting two weeks afterwards – with two review
manuscripts read from the resilience literature, both coauthored by Prof. Marten Scheffer. In both sessions, separated one week, students were taught some case studies on different ecological systems, and learned to draw and logically reason on the concepts of flow diagrams and rates of change. After each of both session, student's capacity to establish logic relationships between ecosystem's components and resilience, was evaluated through a test with 23 polar questions (i.e., TRUE/FALSE). The same test was repeated in both sessions in order to fully evaluate the repetitive nature of the intervention loop. They were also asked to number the number of assigned papers they had read before the session (0, 1, or 2). In both cases, students were informed that the test would be used to assess the teacher's intervention. Hence, the test was voluntary.

III. In the final part, after both sessions, students were asked to write an essay to be handled one month afterwards. The assignment involved a short literature review on any case study on ecological resilience, based on the student's own choice of literature, and a final part where the student had to provide a critic appraisal on the topic, relating his/her subject with the overall theory on Resilience and Population Ecology studied so far during the previous two months. After the marks had been given, students were given feedback on the essay through notes written by the teacher.

While the first and third part are typical from classical approaches in the student curriculum, the Reinforcement Loop intends to raise the awareness of the student on the topic and prepare him/her to think independently with the focus on improving the quality of the essay. In order to evaluate the effectiveness of the Reinforcement loop, correlations between successive variables in the whole intervention were tested. The variables evaluated were the number of assigned papers read in the first and the second practical sessions (Read1 and Read2), the scores in each of the tests in both sessions (Test1 and Test2), and the final mark of the essay (Assignment). Under the assumptions of Ebbinghaus' model, those variables that are closer in time should present more significant correlations, and the final mark in the essay should be higher with the number of assigned papers read before the second session and the test scores during the second session. Trivially, Read1 and Read2 should be correlated by definition (a student can not have read one of the manuscripts in the first session and zero afterwards). Since all the variables are
discrete in nature and are bounded between 0 and some maximum number, residuals are likely to be non-normal. Hence, correlation tests were performed though the use of Kendall's rank-correlation coefficient for non-parametric data with the use of the R package for statistics (R Development Core Team 2009).

![Experimental design in the intervention proposed. The reinforcement loop takes place between the two classical approaches to learning for essay writing. Bold rectangles represent student's own learning actions. Rounded rectangles depict the teacher's actions.](image)

**Fig. 4.** Experimental design in the intervention proposed. The reinforcement loop takes place between the two classical approaches to learning for essay writing. Bold rectangles represent student's own learning actions. Rounded rectangles depict the teacher's actions.

**Results**

Overall, a lack of significant correlations between many pairwise combinations of variables seemed to be prevalent. (Tables 1 and 2, Fig. 5). Only the number of papers read in the first and second sessions of the reinforcement loop was significant, a trivial result as discussed above. However, slightly significant correlations existed between the number of assigned papers read
in the first session and the score of the test in that session ($P<0.1$). Another correlation that deserves mention was that between the score of the second test and the final mark in the assignment ($P<0.15$).

All correlations (whether significant or not) were positive except those related to the second test marks. However, all of them, and especially those regarding the second session, should be taken with care, since the sampling size in that second session was very small (12 vs. 69 students in the first test) due to the volunteering nature of the exercise. Although clearly not significant, the low number of students volunteering for the second test might also be a factor accounting for the weak significance between the mark in this second session and the final assignment.

Table 1. Kendall's rank-correlation matrix between the variables studied in the intervention. Significance levels are depicted by symbols * ($P<0.05$) and · ($P<0.01$).

<table>
<thead>
<tr>
<th></th>
<th>Read1</th>
<th>Test1</th>
<th>Read2</th>
<th>Test2</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read1</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test1</td>
<td>0.169</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read2</td>
<td>0.529*</td>
<td>0.115</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test2</td>
<td>-0.256</td>
<td>-0.065</td>
<td>-0.272</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Assignment</td>
<td>0.015</td>
<td>-0.025</td>
<td>0.108</td>
<td>0.225</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 2. Significance levels for the Kendall's rank-correlation matrix depicted in Table 1. Significance levels are depicted by symbols * ($P<0.05$) and · ($P<0.01$).

<table>
<thead>
<tr>
<th></th>
<th>Read1</th>
<th>Test1</th>
<th>Read2</th>
<th>Test2</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read1</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test1</td>
<td>0.056·</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read2</td>
<td>0.035*</td>
<td>0.332</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test2</td>
<td>0.843</td>
<td>0.610</td>
<td>0.908</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Assignment</td>
<td>0.441</td>
<td>0.607</td>
<td>0.295</td>
<td>0.108</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Fig. 5. Scatterplot matrix between the variables in the intervention. Variables are ordered and colored by significance levels from higher to lower significance (pink, blue, and yellow, respectively).

Partial agreement with the hypothesis concerning divergence with time in regards to memorizing concepts is found in the results. In the first session, most of the students participated, and most of those who participated had still fresh in their minds the previous lectures and the two manuscripts assigned to read, giving a partial explanation for the strong correlations between the number of manuscripts read and the mark in the test. However, one week later, very few students participated, and of those, very few have read again or anew any of the manuscripts assigned, providing no significant and extremely weak correlations for the second test. This is a clear sign of divergence in regards to the information and logical reasoning developed by the students given the longer time elapsed. However, some slight positive trend in the correlation between
this second mark and the assignment appears. This is indeed a positive sign: the presence of the students at the second session, despite the fact that was apparently not related to the marks in the first session, seems to have established the pattern for the assignment, and hence, a more solid framework of logic and knowledge to tackle the rest of the literature that they will read for the final assignment.

Discussion

The results in this study provide partial agreement with the divergence hypothesis regarding the time elapsed between successive interventions to help student ground the framework of a specific subject and avoid the so-called forgetting curve. However, the lack of correlations between both tests (probably due in part to a low number of students taking part in the second session) is counterintuitive. In a sense this is not a major drawback, since the tests are not part of the final assessment of the module, and, as suggested by the weak correlation between the final test score and the essay mark, the second session might have set up the appropriate structure to engage into the literature-based research leading to the essay.

Most of the students had raised comments at the beginning of the module regarding the use of mathematics to explain ecological subjects. In a modified “muddiest point game”, the students expressed some consensus:

"2 much maths Involved!"
"Difficult to write down formulas and listen at the same time"
"Too fast when explaining maths"
"When explaining math models, don't explain all equations"
"Go through the maths equations slower and apply to more 'real' examples"
"Too many equations"
"The equations can get very confusing"...

However, when asked to write potential solutions to the muddiest point, none suggested to eliminate the mathematical approaches, but rather to slow down and explain them better:
"Keep it simple!"

"Explaining statistics at a slower pace would be helpful. Also use formulas on p'wrpoint – NOT the whiteboard please! Relate some topics to how we could expect to see them in and exam”

“Math writing bigger”

“Define the parameters in the equations please”

“Explain math better & make lectures more entertaining”

“Go through equations slower, explaining meanings of letters eg. 'lx' more fully”

“Either put all equations in one lecture or put an introductory line of text on the Powerpoint before going into details on the white board”...

Students' recommendations were followed mostly during the first session of the reinforcement cycle. However, in the second session, most of the lecturing time was dedicated to answers doubts. The doubts the students raised were mostly linked to the format and marking assessment of the assignment. Hence, the apparent lack of correlations in the second test might have been due to the fact that the second session was not a “repetition of concepts” per se, but rather a session of clarifying doubts, possibly reducing the capacity of that session to reinforce knowledge and reasoning.

Repetition of key points helps students to acknowledge the main points of the subject (Brown & Atkins 1987). Particularly in essay writing, repetition further strengthens the links between the initial introductory elements of the subject and the conclusive statements, giving cohesion to the subject (Lea & Street 1998). However, the intention of the exercise was to precisely avoid boredom and unnecessary stereotyped repetition, “the plagues of traditional teaching” (Motschnig-Pitrik & Holzinger 2002). Aware that repetition is often seen negatively (i.e., Kember 2001), the very concept, when embedded into an integrated approach to reinforce learning can become beneficial by moving from surface to deep learning (Shaffer & Small 2004).

The integrated approach taken, trying to combine reinforcement and repetition through self-practice exercises and readings, may not be optimal. A more proper test to evaluate whether
positive reinforcement was in place in the classroom would have involved asking from learners what is their perception of reinforcement, or indirectly search for their level of motivation while they interact with each other and the teacher (Black 1999). But the purpose of this intervention was purely exploratory. From this conception, we can avoid overly exaggerated speculation by taking the somewhat conservative statistical approach in this manuscript and conclude that indeed, for any research-based exercise in the classroom, reinforcement will be most optimal with an intensive intervention in the early stages, followed by another one, probably equally intensive not too later afterwards, enough for the student to have had time to develop a proper structural knowledge on the topic and short enough to keep the level of motivation and self-confidence high and fresh. Furthermore, effective learning in research-based approaches will likely require the introduction of integrated approaches to avoid excess of repetition in models of reinforcement learning (Kirschner et al. 2006). From this perspective, students may approach the structures of research from the very foundations of the research methods by themselves.