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A Case Study of Team-Based Learning for Evolutionary Biology Classes in Biology Majors

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ABSTRACT

The authors describe the experience with a partial implementation of Team-Based Learning strategy, as was carried out in the context of the Evolutionary Biology course, an obligate part of the undergraduate Biology curriculum at the University of Évora. In contrast to previous attempts at turning the students attending this course from their notorious inertia, this strategy finally accomplished a significant unfolding of the students' immediate interest and thence helped them attain a richer learning experience. The recommendations by the developers of Team-Based Learning served as basis for this implementation, which is laid out in protocol format for the present article and illustrated with examples from the themes proposed. The results from a survey on this implementation of Team-Based Learning, made available to the students, gave important feedback for discussion of the strengths and weaknesses in the experience so far. Although this implementation arguably fulfils most of the core elements of the recommended Team-Based Learning procedure, considerations are made on the possible need to upgrade to a full implementation of Team-Based Learning in this course.

1. Introduction

In most Biology curricula there is a course devoted to studying Evolution, not as an accessory to another discipline, such as Zoology or Genetics, but as the main subject, bringing its concepts and approaches to central focus. However, motivating Biology students to appreciate the need to attain a deeper understanding of this discipline can be quite difficult: apart from the unappealing theoretical (and mathematical) content, it seems that they are satisfied with their knowledge, unaware that as biologists they must go far beyond intuitive (mis)conceptions (Coley & Tanner, 2015).

Such was our experience with the students who have been attending the Evolutionary Biology course in our university. We tried to surmount the inertia of most students by motivating them with engaging activities, such as setting up an online forum for the discussion of scientific papers. However, it was always realized that a major shift never happened. Then we decided

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to trial active learning activities in the classroom, and our choice went to the Team-Based Learning (TBL) model.

TBL has emerged, in the last pair of decades, as a worldwide teaching strategy that has been adapted, fully or partially, in a diversity of contexts (Haidet et al., 2014; Parmelee et al., 2012). Its philosophy and core elements are abundantly covered by the original proponents and their co-authors (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992), and guidelines for implementation, namely in Health Sciences education, have been proposed (Haidet et al., 2014; Michaelsen & Sweet, 2008b; Sibley & Parmelee, 2008; Burgess et al. 2020). It was originally conceived as a practical means to promote small group learning in the context of large classes, with a highly structured set of rules for implementation, in order to achieve, primarily:

- student engagement in learning activities,
- promotion of collective (team level) abilities and the inherent reliance of team members on them, i.e., “team cohesiveness” (Michaelsen & Sweet, 2008b),
- improvement of student satisfaction with learning,
- improvement of course content mastery by the students, with the highest effect on less proficient students,
- capacities for using course content in real life, and to experience the added power of teamwork for solving difficult problems.

TBL can be made to replace the conventional lecture format and individual exams altogether, with provisions to make each student accountable, while being committed to participate in team success. In parallel, the transformative nature of the team learning process (Michaelsen & Sweet, 2008b; Fink, 2004) is predicted to drive the development of generalized abilities such as cooperative behavior, or the «practice with concepts in messy, uncertain application exercises» (Parmelee et al., 2012).

Thus, the choice for TBL was made on the expectation that it would help developing the students’ capacities from several angles. It is conceived as a series of sessions, each centered on a major topic of the program, through which the students, always integrated in the same team, are challenged to solve problems by prizing collaboration to achieve their goals. The structure of each session, as documented in many sources (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011), consists of: i) a preliminary introduction of the relevant topics, off class, ii) the Readiness Assessment Process (RAP) that tests, in class, the preparation for the module, first individually and then by the teams, iii) a summary, the grading and appeals on the RAP answers, finally leading to iv) the team Application, where a significant problem within the scope of the module is presented, for solution by all teams in the class. The repetition of this process over a number of sessions, with a variety of problems that cover the course program wholly or in part, promotes a parallel realization of the team intellectual resources, through recognition of interdependence and cohesion buildup, directed by the need for them to thrive in face of the posed problems (Michaelsen & Sweet, 2008b).

The present communication gives an account on our initial experience with this mode of group learning, which we have implemented in an abridged form and in complement to conventional lectures and an exam. This partial adaptation is described in detail and confronted with student feedback, in order to help discuss its use and the prospect of taking the step toward a full implementation of the TBL strategy in this Evolutionary Biology course.

2. Materials and Methods

2.1. The Implementation

2.1.1. Overview

At the University of Évora there is a strong recommendation for allowing students the option between final exams and continuous assessment. The TBL activities were part of the continuous assessment only, and even then, contributed only partially to the final grades, being complemented by partial exams.

Our experience so far comes from the Fall-Winter semesters of 2016, 2017 and 2018, the first two with 15 weeks available, the latter with 14 weeks. There were 6 TBL sessions in 2016, 5 in 2017, and 10 in 2018. This variability was in part due to an update of the Biology curriculum after 2016, and our decision to settle in a higher number of sessions after 2017. The sessions took, on average, 90 minutes.

Students had to be present at a majority of the TBL sessions to be able to complete the continuous assessment. Missing any sessions penalized the cumulative calculation of the TBL component. TBL had a 60% weight in the final mark by continuous assessment in 2016, but the lack of investment of those students in preparation for the exams, as well as the need to put more weight in individual assessments, led us to settle on a 50/50 proportion since 2017.

This is a partial implementation, because not all specifications of TBL were followed, though striving to retain the essential aspects of a full-blown TBL practice. Thus, instead of a preliminary Readiness Assurance Process based on written tests, the sessions moved directly to the Application sequence, with oral presentation of the answers. Still, a separation of individual- and team-based phases of preparation was kept.

The assignment of students to teams was always such that 6 teams were formed, consisting (depending on the attendance of the year) of 4 to 6 members each. In our experience, a team should work with at least 4 members consistently. As recommended by the TBL model, their composition was designed to optimize the attainment of important landmarks in the TBL process. In the absence of any apparent social/ethnic/religious heterogeneities to account for, the teams were formed based on the knowledge of previous behavior in other courses, namely:

i. Personal affinities, such that students customarily working together are split over different groups, to avoid the disrupting effect of coalition (Michaelsen & Sweet, 2008a, 2008b, 2011);
ii. Grades in related courses (Zoology, Botany, Genetics, Molecular Biology…), to avoid the concentration in the same team of students expected to be more skillful;
iii. (Since 2018) The likelihood of some students to skip sessions, so that the potential absentees were evenly distributed over the different teams.

2.1.2. Protocol Followed for Each Session

1. A few days before, documentation relevant to the topic, but without hinting on the actual question to be analyzed, is made available online.
2. At the beginning of the session, the context of the question is set forth by the teacher, usually with the support of projected images. Then the actual question is posed.
    a) In our implementation, and according to recommended practice (Michaelsen & Sweet, 2008a, 2008b, 2011), the question requires a decision type of answer (true/false, A vs. B, etc.), but at the same time is open-ended in the explanation it requires.

   b) It is preferable that the students are not assembled in their teams before step 4, so that their initial approach to the question is truly individual.
3. A brief time is allowed for each student to take notes and request clarifications individually, in order to develop own ideas about the question to be answered by the team.
   a) This is analogous to the individual Readiness Assurance Test (iRAT), but in our implementation it is designed to allow each student to formulate ideas to contribute to the team; no answer is known by the teacher at this point.
   b) The teacher must be available for clarification of any points raised by the students.
4. The teams assemble, and the members of each team have a longer time to exchange views, with the objective of achieving a consensus on the answer.
   a) The teacher must be available for clarification of any points raised by the students.
   b) It is advisable for the teacher to give a time notice so that all teams finish off their work.
5. The teacher starts the discussion, by asking what the answers were.
   a) This is analogous to the team Readiness Assurance Test (tRAT), but the answer is oral.
   b) According to recommendation (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011), one should begin by asking for the answers simultaneously to all teams, which is easy to do in a decision type of answer (such as each team's representative raising the hand at the choice taken); only afterwards are the explanations delivered, each team in turn. For the latter step, the initial group should be different from one session to another.
   c) If the teacher finds some arguments to be somewhat unclear, a clarification is requested, but at the same time leaving the discussion to the teams.
6. The teacher, who has refrained from participating in the discussion until now, summarizes it and complements as found necessary, discussing any points raised by the teams at this stage in order to achieve a consensus.
7. The teacher grades the teams on the spot (we do it on a percentage scale) and closes the session.

The Appendix to this article lays out two examples of application of this protocol in our Evolutionary Biology course.

2.2. Survey and Statistical Analyses

The idea of obtaining feedback from the students only materialized in 2017, but at least part of the students of 2016 was reached, so that they could contribute their responses. An online survey (https://biologiaevolutiva.typeform.com/to/bKsGeK) was designed such that each respondent would be able to assess own impressions on the difficulties, the effectiveness of the teamwork, performance of the class, and satisfaction levels. Except for a question on team improvement (Yes/No answers) and an open question for facultative commenting, responses were in the form of ratings from 1 to 5, which were, for statistical analyses, modified to a commensurate scale from –2 to 2, so that 0 would represent a neutral answer. The feedback form was made available to the students each year, starting in 2017, after the last exams were completed.

Statistical analyses were made using the JASP program in Windows (JASP Team 2022, https://jasp-stats.org). Comparisons were made between the two groups of students according to their responses to the question on team improvement, using the one-sided Mann-Whitney U test (with the Rank-Biserial Correlation r for the effect size) and the Vovk-Sellke Maximum p-Ratio (MpR, with the corresponding two-sided p-value).

3. Results

3.1. Participation and Readiness

Regarding participation and readiness, these TBL activities outmatched, by an enormous stretch, all other strategies that were tried in our previous experience with this course. The degree of participation was very satisfactory, with a narrow minority of attending students who remained idle in the team phase of the protocol. Yet, in 2017 a few teams were reduced to a low number of elements (three or less) in some sessions, which hurt their performance and progress alike. This concern was consistently raised by the students that year, thus prompting the need, in years to follow, for scattering the likely absentees over different teams (criterion iii. for building the teams, see Materials and Methods section I-A).

In all years, but most especially in 2018, there was a marked contrast of attendance, between the TBL sessions and the conventional lectures. Besides the requirement for attendance at the TBL sessions, in order to be eligible for continuous assessment, within-team solidarity was a determining factor.

Readiness, though not assessed in written tests, was also a major achievement. Many students did take the time to prepare for each session, as recognized from their capacity to understand the questions posed, the lack of questions on basic topics (which were either already answered, or answered within the team), and the substance of the argumentation. Such behavior was consistent between sessions and among years, except for some teams in 2017 that did not have enough members attending.

3.2. Academic Results

In this respect, the variability between years was too high. For example, in 2016 there were 37 students (out of 41) who completed the course by continuous assessment, while in later years only about 1/3 did so; in contrast, the students in 2016 had a very low average grade in the continuous assessment written test, while in later years the grades were rather positive. These sharp contrasts, with unchanged assessment models, probably reflect specific patterns of behavior (generational shifts, even) that confound any attempts at detecting an influence of the TBL activity on academic performance. But the feedback we have obtained from the students was informative also on this topic (next section).

3.3. Student Feedback

A total of 39 validated responses were obtained, the response rate being 24% for the students of 2016, 50% for those of 2017, and 48% for those of 2018. Table 1 summarizes the results.

Table 1.
Summary statistics of the responses from the students

Topic	**2016 (n=10)**	**2017 (n=15)**	**2018 (n=14)**
Difficulty of the questions (iRAT)	0.7	0.4	1.1
Difficulty of the questions (tRAT)	0.4	0.0	0.4
Team improvement through sessions	60% Y	67% Y	79% Y
General performance of the class	–0.4	0.0	–0.1
Satisfaction with own team performance	0.0	0.0	0.0
Role in motivating for learning Evolutionary Biology	0.2	0.3	–0.3
Composition of the team an enriching experience	–0.5	0.3	0.3

The results from this survey are on a first impression mostly neutral, and this must serve as warning against any one-sided enthusiasm with this experience. The students were not that impressed with the performance of their team, or of the other teams at any rate, even if recognizing that the questions were not too difficult after being worked on collectively.

It appears, however, that this activity has shown progress through the years, judging from the team improvement topic (Table 1). And team improvement seems to be an indicator for favorable ratings of all other questions, in some of them quite strongly (Table 2). Of note, the average levels mostly below neutral, by the respondents who did not acknowledge team improvement. Thus, it seems that, although there is still a lot of room for improvement, our growing practice and the adjustments that were made have helped obtain slightly better results.

Table 2.

Indicators of differences between the group of respondents who acknowledged an improvement of their own team (27 Yes) and the remainder who did not (12 No), all years combined

Indicator	**Average, Yes**	**Average, No**	**Statistic**	**Effect size**	**Interpretation**
Difficulty difference (iRAT – tRAT)	0.67	0.17	$U = 213.5$ $p = 0.035$ MpR = 1.96 (0.071)	$r = 0.318$	Own team improvement may be associated with a widened difference
Performance of the class in general	0.00	–0.50	$U = 215.5$ $p = 0.043$ MpR = 1.74 (0.086)	$r = 0.330$	Own team improvement may be associated with perceiving a better performance
Satisfaction with own team performance	0.26	–0.50	$U = 244.0$ $p = 0.004$ MpR = 9.46 (0.008)	$r = 0.536$	Better satisfaction is associated with own team improvement
Role in motivating for learning Evolutionary Biology	0.37	–0.42	$U = 233.5$ $p = 0.013$ MpR = 3.97 (0.025)	$r = 0.441$	Motivation for learning is associated with own team improvement
Composition of the team an enriching experience	0.44	–0.75	$U = 261.5$ $p < 0.001$ MpR = 34.8 (0.002)	$r = 0.614$	Perception of an enriching experience is associated with own team improvement

A few respondents used the opportunity to express further aspects, as exemplified in Table 3.

Table 3.

Examples of phrases contributed by respondents, arranged by the response to the team improvement question, with indication of the year of attendance

Team improvement: Yes	**Team improvement: No**
«I was lucky to be in a group whose members did not miss the sessions, came prepared and discussed with logic… other groups that did not function well were unsuccessful, and this created a bias in the final marks» (2017) «A better balance in the group composition is needed so that by the end all teams are functioning» (2017)	«Smaller groups so that all members can be more active» (2016) «These exercises will work only with all team members always or almost always present» (2017) «The surprise element in the question can be refreshing/interesting, but must not be exaggerated… this is my only remark, apart from that … I am thankful for this initiative» (2018)

4. Discussion

There are two main aspects of this discussion: the *a priori* merits of our implementation of the TBL model, especially for our introduction of several adaptations; and the outcomes of this activity, both from the point of view of the conveyed satisfaction, and from the academic performance of the students.

4.1. The Adaptations

The tendency for adopting TBL only by 'bits and pieces' seems to be widespread, with a veiled criticism from the promoters of this strategy (Parmelee et al., 2012). In the present experience, we ensured that most of the key elements of TBL were integrated: team formation rules, preparation by each student in advance, the '4-S' criteria in the Application questions (be Significant, the Same for all teams, Specific, and with Simultaneous response), in-class team activities taking most of the TBL time, and immediate feedback (Haidet et al., 2014; Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992). What was left aside were the written evaluations and appeals of the Readiness Assessment Process, focusing essentially on the team Application task. Nevertheless, as pointed out in the Materials and Methods, our version of the RAP kept a separation into individual and team phases, in a manner analogous to the iRAT and tRAT steps, respectively, so that the students would perceive the power of team collaboration. This shortening of the TBL protocol was a practical decision on our part, since we wanted to reduce the length of the sessions. Furthermore, our choice of building each session entirely on the Application question allowed a more straightforward emphasis on real-life problem solving in a team context, which is central in TBL. It is at this phase of the procedure that discussion, deliberation, and response articulation demand higher order thinking skills, especially if the problems faced are too difficult for any student to tackle them individually (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992).

Bypassing any individual grading, as we did until now, may give rise to a sense of injustice, not only for the so-called 'free-loaders' who contribute virtually nothing to their teams (Fink, 2004), but especially for those who skip sessions repeatedly and undermine the vitality and growth potential of their team, a problem that we did not foresee in 2017 and was pointed out by all comments shared that year in the survey (Table 3). This experience has shown that individual grading by exams does not mitigate the sense of injustice.

Moreover, the exam results did not reflect a stimulus to performance by the TBL sessions: in 2016 the students did not invest their time in preparing for the exam, and in 2017 and 2018 only a minority completed the continuous assessment option. Peer evaluation is instrumental in making students individually accountable within the TBL strategy (Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992; Burgess et al. 2021) and is not properly replaced by complementary evaluations.

Thus, it is an essential part of a skillful fashioning of team composition to scatter students that are judged likely to become absentees in order to minimize the possibility of some teams being hurt by such behavior more than others. Knowing the students in advance, for their conduct in previous courses, is an important guide, but nothing can be taken as foolproof and adjustments may be necessary at the beginning of a session, such as merging two fragile teams, or transferring one student from one team to compensate the losses in another team. Such reaction to circumstances ought to be done conservatively in order to reduce the negative impact on 'good' teams.

One of the distinctive aspects of the whole TBL protocol is the manifold of feedback-rich learning experiences (Parmelee et al., 2012), from the point of view of students and teacher alike. The teacher-turned-to-manager (Michaelsen, 1992), released from focusing on content delivery, will direct the attention more to the aspects that drive team success, and this goes much beyond a vigilance over team attendance.

As indicated for the team Application phase (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992), a great part of the merit by each team hinged also on the quality of the argumentation supporting their answer. With our emphasis on this phase we valued argumentation in two ways: as a demonstration of having explored the question as deeply as possible in order to build the best judgment, and through the oral expression of the arguments, shared with the class (Michaelsen & Sweet, 2008b; Michaelsen, 1992). While it is expected that all groups take the right decision, it is unlikely that their explanations are identical, and this practice of answering orally motivates the search for complementary points of discussion that will not be covered by other teams, which are the ‘threat’ element that encourages transcendency (Michaelsen & Sweet, 2008b). The progress by each team, besides learning how to make the right decision, is felt also in this motivation for enlightening their peers. And, by knowing in advance that the quality of the discussion will have the potential of moderating the consequences of a false decision, that search becomes engaging. During the discussion, even if the team realizes that their decision was the wrong one from the points made by other teams, they should at least be able to point out how they reached their conclusion, which is a very constructive way of contributing to the session, also giving the teacher more matter for the summarizing step.

4.2. The Outcomes

Turning from apathy to a spontaneous engagement in solving questions of Evolutionary Biology, a better development in this course could hardly be imagined. Seeing the students almost literally ‘come to life’ in the classroom, thinking, working, discussing, was a highly rewarding experience, one that only came, in the Evolutionary Biology course, with the TBL sessions that we set up. Yet, from the students’ point of view, satisfaction was quite variable.

We still endeavor to make this activity satisfying for all students who participate regularly, and a more thorough explanation of what the students and their teams will be facing can be helpful (for example, with a TBL sample session, Parmelee et al., 2012). Our evidence, from the survey, that students who felt an improvement of their team as the semester progressed also felt, if at an intermediate level, more motivated to study Evolutionary Biology (Table 1), encourages us to obtain better results with this activity, in the belief that it will propagate through other aspects of the evaluation, and to some extent also into their development as future biologists. Team improvement was shown to be a wide-ranging indicator for success (Table 2), confirming the far-reaching consequences of turning into an advantage a team composition that goes against the students’ habitual setting, as it involves creating a unique blend of intellectual resources capable of thriving amid daunting problems (Michaelsen & Sweet, 2008b; Michaelsen, 1992). Some students are more willing than others to accept such challenges (Fink, 2004); however, given the importance of context in the decisions that are made (Gouvea & Simon, 2016), the difficulties encountered encourage their need to trust in team strengths.

The overall performance in the course is yet to show a perceptible improvement, and the results from the survey are at a moderate level of success with the TBL initiative (Table 1). Hence our admission that there is still much room for progress.

The results so far point up two needs, foremost with the goal of enabling team cohesion and growth:

- Perfecting the team composition, according to the three criteria outlined in our description of the implementation, and
- Staying aware of the need to react to the circumstances, so that the whole TBL activity becomes effective.

The incorporation of missing parts of the TBL procedure, namely peer evaluation and an efficient incorporation of the written tests, is an important consideration to make, especially for the need to support persistent learning. This transitional implementation helped us perceive the enormous potential of TBL for winning back students who, in the conventional setting, feel lost from their motive for learning. Outstanding is the whole experience of discovering unforeseen rapport with less than usual peers, since it has highly meaningful links to many situations in professional life (Sibley & Parmelee, 2008).

5. Conclusions

Our initial goal of providing the students with an effective outlet for active participation was repeatedly attained, but what can we do with this experience? Since TBL is claimed to have a much deeper potential as a learning strategy, especially for engaging higher order cognitive skills (Michaelsen, 1992), we feel almost compelled to give more room to this component of our Evolutionary Biology teaching. However, as a teaching tool, TBL can take its time to be mastered. Hence our view of this experience as a transition, one that helped us grasp such claims. And we agree with the TBL creators (Michaelsen, 1992) that the course content need not be sacrificed to any extent by completing this transition.

We feel that TBL is best applied when exercised continuously, such that closing one TBL session is followed by the start of another. If only part of the semester is devoted to TBL activities, these should be carried out avoiding interruptions by conventional lectures. The specifics for every aspect of the strategy are clearly described in a variety of publications (Parmelee et al., 2012; Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992; Burgess et al. 2020), and with the experience we have so far, the structural adaptations to introduce (setting up a classical RAP, separately from the Application phase, and including peer evaluation) are not that much of a challenge. The real challenge lies in two non-structural, albeit structurally contingent, goals: achieving a real improvement process with all teams and, with it, make the TBL strategy an efficient passage for the mastery of course contents by all students. Student accountability is argued as a very important means to achieve this (Michaelsen & Sweet, 2008a, 2008b, 2011; Michaelsen, 1992; Burgess et al., 2021), hence the worthiness of peer evaluation in succeeding with TBL.

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Appendix

Examples of Implementationin the Evolutionary Biology Course

The following examples are meant to illustrate effective team assignments (Michaelsen & Sweet, 2008b) in our Evolutionary Biology course. The numbered paragraphs relate to the steps of the protocol in Materials and Methods.

Genetic Introgression

1. The research paper (Fitzpatrick et al., 2010) is distributed online, with the indication to relate its Figures 1 and 2, and 2 and 4. Paper Figure 1 is a map of the sampling sites covering the natural range of California Tiger Salamander, *Ambystoma californiense* Gray, over a 200 Km transect extending from the point of contact with the Barred Tiger Salamander, *Ambystoma mavortium* Baird, deliberately introduced decades ago by fishermen to use their larvae as bait. Paper Figure 2 shows that genetic introgression into the threatened species *A. californiense* (a consequence of hybridization) is well below 50 Km from the contact zones, except for 3 gene markers that extend to 150 Km. Paper Figure 4 illustrates a region near the contact zone where the contrast between markers is more acute, with those 3 markers practically fixed in all sampled ponds, and the remainder 65 showing no signs of introgression beyond 2 Km away from the supposed introduction site.
2. In class, pictures of both species are displayed, and the information on the article reviewed. The question is, which hypothetical aspects of the biology of the hybrids (and their descendants) may explain the geographic extent of the 3 spreading genetic markers: a) high mobility, b) high survival, c) high reproduction, or d) introgression still incomplete?

The students will soon notice a paragraph in the article analyzing the existing knowledge on hybrid fitness in this case. However, no direct answers to the question are available in the paper. Teams are stimulated to discuss introgression dynamics, life cycles, fitness components, management dilemmas.

6. Of the four answers to choose from, there is more than one that can be correct. The main point for the students to bear in mind is the simultaneous inheritance of all markers, but the divergent outcomes among them. The genetic background, represented by 65 markers, clearly points to a short range of dispersion of the *A. mavortium* genetic materials present in the hybrid lineage. So, the high mobility, even if true, would be immaterial for the question. The reason for fixation of the 3 divergent markers is selective advantage, which would suggest good arguments for high survival and/or high reproduction. Option d), incomplete introgression, is obviously true since these 3 markers are absent from the most distant parts of the 200 Km transect; however, it is a less interesting choice because it falls short in approaching the selective advantage issue; of note, a team that chooses this answer is implicitly against the hypothesis of high mobility.

Comparison Between two Phylogenetic Trees

1. Instead of a research paper, the students are supplied in advance with a text on the process of building phylogenetic trees from molecular sequence data, so that they can recollect their previous knowledge on the subject (in this case, both from the introductory activities at the Molecular Biology course in the previous semester, and the previous theoretical session, in this course, on building cladograms).
2. A quick review of the materials provided is made, allowing clarifications before entering the topic. Subsequently, the teacher presents two cladograms built from the same set of ingroup sequences, differing only in the outgroup used (two platyrrhines in A, two murines in B), with rather similar results (Figure A1). Further information necessary to understand the cladograms (as given on the note to Figure A1) is provided. The question is: which of the trees, A or B, is more correct?

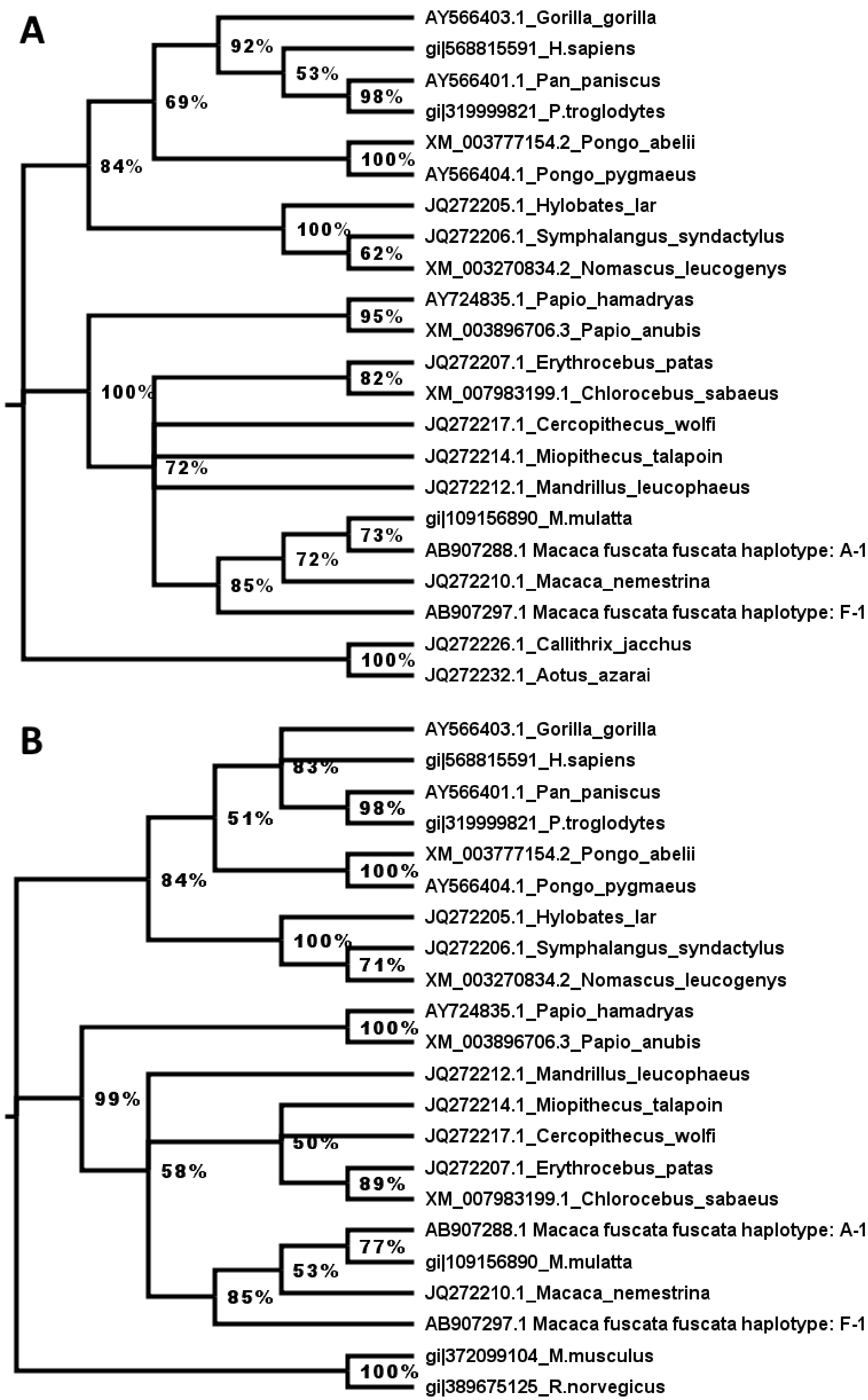

Figure A1. The two cladograms to be compared

Note. Trees built from the DNA sequences of gene *TAS2R38* in several catarrhine (primate) species, and the significance of each node was tested by a bootstrap procedure (500 replicates). Only the nodes with a bootstrap support of at least 50% were retained. Tree A, outgroup formed by platyrrhine (primate) species; tree B, outgroup formed by murine (non-primate) species. Sequences retrieved from the NCBI Taxonomy portal on November 7th, 2016 (https://www.ncbi.nlm.nih.gov/taxonomy). Alignment and tree construction done with the MEGA software package version 7 (Kumar et al., 2016), and tree rendering made with Figtree software version 1.4.4 (http://tree.bio.ed.ac.uk/software/figtree/).

6. The correct answer is the A tree, because a more accurate context for the ingroup topology is brought by a closer outgroup (non-catarrhine primates in A, by comparison with non-primates in B). Accordingly, with a relatively distant outgroup there is too much genetic variation — with a greater load of uninformative, and in many cases reverting, traits — exclusively belonging to the diverging branch containing the outgroup. The fact that some of the groups in the B tree are unresolved in tree A is of little importance, given that the criterion for 'supporting' a group is arbitrary (in the example, ≥ 50%) and such groups in tree B have a support barely above it.