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Evolution MegaLab: a case study in citizen science methods

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Summary

1. Volunteers have helped in scientific surveys of birds and other organisms for decades, but more recently, the use of the Internet has enormously widened the opportunity for citizen science and greatly increased its practice. There is now a need to share experience of which methods work and which do not. Here, we describe how we planned and executed the Evolution MegaLab, one of the largest surveys of polymorphism in wild species so far undertaken.

2. The aim of the Evolution MegaLab was to exploit the occasion of Charles Darwin's double centenary in 2009 to mobilize the widest possible section of the general public in Europe to help survey shell polymorphism in the banded snails *Cepaea nemoralis* and *Cepaea hortensis*. These data were then compared with historical records to detect evolutionary change that may have taken place in the decades between samples.

3. Records of polymorphism in over 7000 populations sampled throughout the natural range of the two species were captured from published and unpublished sources and added to an online database. These data could be explored by the general public *via* a Google Maps interface on the project website (http://evolutionmegalab.org). The website contained a welcome page that explained what evolution is and how recent changes in climate, and the abundance of predatory birds (song thrushes *Turdus philomelos*) might have caused an evolutionary change in the shell patterns of banded snails.

4. A network of collaborators in 15 European countries was formed, with each country responsible for translating the website and associated materials, recruiting volunteers and raising any funds required locally. A total of 6461 users registered with the site, and 7629 records were submitted. We used an online quiz to train users and to test their ability, to recognize the correct snails and their morphs. Every user received automated, immediate feedback that compared their data with nearby records from the historical database.

5. The critical tasks achieved by the Evolution MegaLab that any citizen science project must tackle are as follows: (i) design of an appropriate project, (ii) recruitment, motivation and training of volunteers, and (iii) ensuring data quality.

Key-words: Ecological genetics, evolutionary biology, population genetics

Introduction

Citizen science projects invite the public to take part in scientific investigations by contributing data, processing data or both (Silvertown 2009). Citizen science is of growing application in environmental sciences because volunteers can be recruited from and can sample over, a very wide geographic area and can do so more quickly and at lower cost than a professional research team (Dickinson, Zuckerberg, & Bonter 2010; Conrad & Hilchey 2011). The largest projects that gather biodiversity data from the general public are in the field of

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ornithology, with surveys such as eBird (Sullivan *et al.* 2009) or Audubon's Christmas Bird Count (Butcher & Niven 2007). These projects take advantage of sightings that birders make of their own volition (eBird) or under direction from project organizers (the Christmas Bird Count). Such bird surveys have proved invaluable for detecting trends in population numbers over time (Magurran *et al.* 2010; Thaxter *et al.* 2010). Other surveys utilize the reach of the citizen science approach for surveillance of invasive organisms and their spread (Delaney *et al.* 2008; Crall *et al.* 2010; Gallo & Waitt 2011) and for mapping vegetation (Brandon *et al.* 2003; Galloway, Tudor, & Vander Haegen 2006; Jacobson *et al.* 2006; Oscarson & Calhoun 2007) or other natural resources (Nerbonne & Nelson 2004; Sharpe & Conrad 2006). It is unusual for citizen science projects to address evolutionary questions, although some early examples in the UK have done so (Cook, Mani, & Varley 1986; Crawford & Jones 1988).

Each project will use methods appropriate to its own specific field of enquiry, but there are also certain requirements that all citizen science projects have in common and about which it is useful to share experience. These common denominators boil down to three basic requirements that arise whenever volunteers are used: (i) the methods must be designed with the capabilities of volunteers in mind; (ii) volunteers need to be recruited and, as part of the same process, motivated; and (iii) the data collected need to be validated. The purpose of this study is to describe how we met these challenges in the case of the Evolution MegaLab (http://evolutionmegalab.org), a large, international project that operated in 15 countries in Europe.

The aim of the Evolution MegaLab was to exploit the opportunity of Charles Darwin's double centenary in 2009 to mobilize the widest possible section of the general public in Europe to help survey shell polymorphism in the banded snails *Cepaea nemoralis* and *Cepaea hortensis* (Fig. 1). These data were then compared with historical records to detect evolutionary change that may have taken place in the decades between samples. *Cepaea* was chosen for the project because the two species are widespread and abundant in Europe, most populations are visibly polymorphic, and the volume of existing data and research on evolution in *Cepaea* is very substantial (Jones, Leith, & Rawlings 1977). From the point of view of a citizen science project, it was also important that the animals are safe to handle, would not be damaged by handling or endangered by over-collecting, and that the evolutionary hypotheses we set out to test were topical and easy to explain. The scientific results of the project are reported in full elsewhere (Silvertown *et al.* 2011).

Fig. 1. Polymorphism in a Polish population of the banded snail, *Cepaea nemoralis*. Photograph courtesy of Robert Cameron.

Methods

PROJECT DESIGN

As soon as initial funding for the UK project had been secured (2½ years before the public launch in March 2009), we recruited a scientific committee of *Cepaea* geneticists to guide the detailed design of the project and to participate in the analysis of results (Silvertown *et al.* 2011). The scientific committee also compiled the historical data set from published and unpublished sources. Collaborators in 14 countries outside the UK were found through personal contacts and most attended a co-ordination meeting in London a year before the launch. Collaborators in each country were responsible for translating the website and associated materials, recruiting volunteers and raising any funds that they required locally.

We advanced two hypotheses for the Evolution MegaLab to test. The first related to climate change and proposed that the frequency of lighter-coloured shells (yellow as opposed to darker colours) would have increased in the last 40–50 years because a shell with a higher albedo would be favoured in a warming climate. The second hypothesis was related to bird predation on *Cepaea* and proposed that the established correlation between habitat (woods vs. open areas) and colour morph (historically, darker colours were more frequent in woods) would have weakened in areas where song thrushes (*Turdus philomelos*) have declined in abundance (e.g. England) because in these places, cryptic shell colours would no longer be important for camouflage against visually searching bird predators.

Variation in shell colour and banding in *Cepaea* is controlled by a number of major loci, but is also modified by others that can make some phenotypes difficult for amateurs to score accurately. We, therefore, selected just three traits and their commonest states for use in the Evolution MegaLab: shell colour (yellow/pink/brown), banding (present/absent) and band number (1/ > 1).

The Evolution MegaLab website was fundamental to the whole project. The open source software framework Symfony (http://www.symfony-project.org/) was selected to build the back-end of the website because it was well supported and catered for the easy production of versions in different languages by collaborators. All language versions were hosted centrally at the Open University. When the final version of the Evolution MegaLab website was launched in March 2009, there were versions in Catalan, Dutch, English, Estonian, French, German, Hungarian, Italian, Portuguese, Polish, Spanish, Latvian, and Welsh as well as additional, country-specific versions for Austria and Switzerland. Videos illustrating the use of the website are included as Supporting information.

The specification for the website was developed from a scenario of how we envisaged a naive user, for example, a school student, would interact with the site. A beta version was available 18 months before launch and was tested publically under an alias to preserve the name 'Evolution MegaLab' for the launch in 2009. The landing (Home) page explained in simple terms what evolution is, that evolutionary change occurs through the gradual accumulation of small, inherited changes and that it is possible to see evolution happen if you compare records from the past with modern observations. The page was illustrated with photographs of *Cepaea* shells of various colours and banding patterns. The two hypotheses were explained, and the visitors were invited to help us test them by taking part in the Evolution MegaLab. The historical data and the new data collected by users were displayed on separate Google Earth maps, with pie charts showing the frequency of colour morphs. Users could drill down from an overview of frequency variation across Europe to individual records where details could be displayed in a pop-up. Users were encouraged to explore the map of their neighbourhood to find the location of populations that had been sampled in previous decades and then to resample these sites. Downloadable documents provided: a sampling protocol that standardized search effort, an identification guide, a recording sheet, notes for teachers, resources for use in the classroom and a more advanced guide to the genetics of shell traits in *Cepaea*.

Before going out to sample, we asked users to register by providing a user name, a verifiable e-mail address and a password and then to take a quiz that helped to train them to recognize the correct snails and morphs. More details about the quiz are given later in the sections on data quality. The data input page of the website was laid out identically to the recording sheet provided for field use, with each input field illustrated with an image of the snail morph being counted. In addition to counts of each morph for each species, we asked users to indicate the habitat in which they had sampled from a choice of four types in a drop-down menu and to pinpoint the location of their sample on a Google Earth map provided.

Users were provided with immediate feedback on their results on the screen and by an e-mail sent to their registration address. Feedback included bar charts and pie diagrams and comparisons with historical data where any had been collected within a radius of 5 km of the sample submitted. An automated interpretation of the results was provided using an algorithm that customized the text based upon the distance between samples, which habitats were sampled and a chi-square test performed on counts (if sample size permitted). The feedback was also added to the pop-up for the new sample, so that others could also view it.

RECRUITMENT OF VOLUNTEERS

The project was planned from its inception to be suitable for use in schools, by university students and by members of the general public. All participating countries used the Evolution MegaLab name and website and translated the site and materials for their own national audience. Separate publicity campaigns were mounted in each country, using a common pool of resources such as images, identification guides and resources for schools. Some collaborators found local funding for promotional materials or partnered with other organizations to promote the project. All benefitted from the international recognition of the significance of 2009 as Charles Darwin's double centenary, although of course this had greatest resonance with the public in the country of his birth. In the UK, we used national and local print media, features on network television, interviews on local and national radio and stands at conferences for teachers, scientists and the general public to promote the project.

DATA QUALITY

We controlled the quality of the data submitted by the public by means of both presubmission and postsubmission measures. The presubmission measures were designed to avoid errors being made, while postsubmission measures were designed to identify errors and where necessary remove erroneous data (i.e. to 'clean' the data). Presubmission measures included sampling only those traits that are easy to score and instructing users to record only adult *Cepaea* (which have a well-formed lip to the shell) because amateurs have difficulty telling juvenile snails of the two species apart. We also chose a classification of habitats that was slightly simpler than the one normally used in the *Cepaea* literature, but which could be matched with it. The habitat categories woods/hedgerows/grassland/sand dune that we used were distinct enough to be recognized and corrected from Google Earth imagery if a doubt arose as to a participant's use of the classification. To aid snail identification, we provided video instructions on the website and well-illustrated field guides. These were customized by region to allow for the fact that *Cepaea* had to be differentiated from a snail fauna that varies across Europe.

The online quiz provided a means of controlling data quality both before and after submission. Before submission, it helped train users to recognize the correct species and identify morphs correctly. The following five questions were covered: (1) distinguishing *Cepaea* from similar species, (2) distinguishing between adult and juvenile *Cepaea*, (3) distinguishing between *C. nemoralis* and *C. hortensis*, (4) identifying shell colour and (5) identifying shell banding pattern. Users were given three attempts at each question with increasingly more detailed feedback being given each time they got a question wrong. A new set of relevant images drawn from an image bank was presented for each attempt. We saved users' quiz scores against their user names so that when they submitted data, it would be possible to weight the data in our analysis by users' measured ability to identify species and morphs correctly.

Although participants were encouraged to revisit sites for which we had historical data, we did not insist on this because we wished to maximize the number of records submitted and because new locations could increase the range of reference points available for future surveys.

Results

RECRUITMENT OF VOLUNTEERS

Traffic to the website was monitored using Google Analytics. During the active phase of the survey in 2009, there were 108 836 hits on the site and 71 232 unique visitors from over 140 different countries. In total, 6461 users registered with the site (an additional 731 users registered with the site but did not activate their account, possibly because they had submitted an invalid e-mail address). 7629 records were submitted by 2472 registered users (Fig. 2).

The most successful publicity campaigns, measured by the number of users registering on the website, were the UK (2935), Germany (1833), Switzerland (466) and the Netherlands (381). The project obtained local funding in each of these countries, and in the UK and Germany, this supported a full-time member of staff dedicated to the promotion of the Evolution MegaLab. The Netherlands had staff from Naturalis and the Netherlands Institute for Biology working to co-ordinate, promote and recruit volunteers and Switzerland recruited members of Bird Life Switzerland. In the UK, The Open University ran a level one course called 'Darwin and

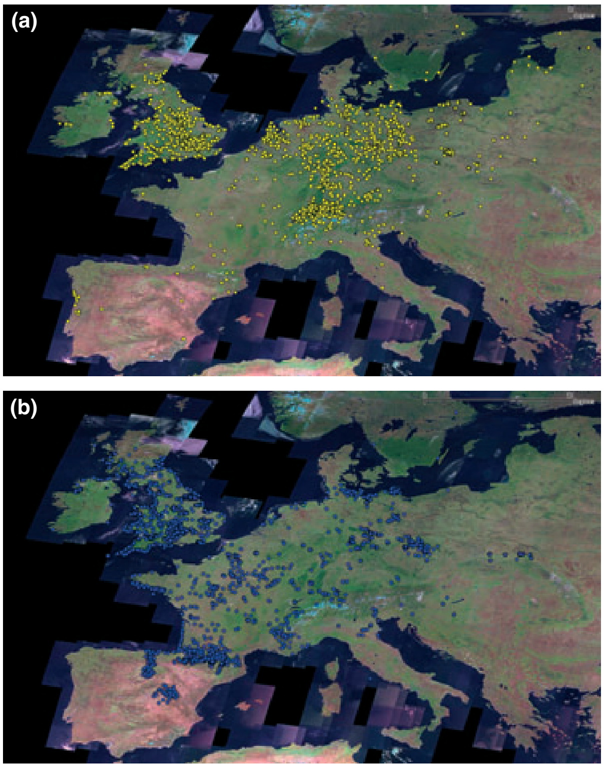

Fig. 2. Geographic distribution in Europe of records of *Cepaea* polymorphism (a) submitted to the Evolution MegaLab website in 2009 (n = 7269) and (b) in the historical data set used on the Evolution MegaLab website.

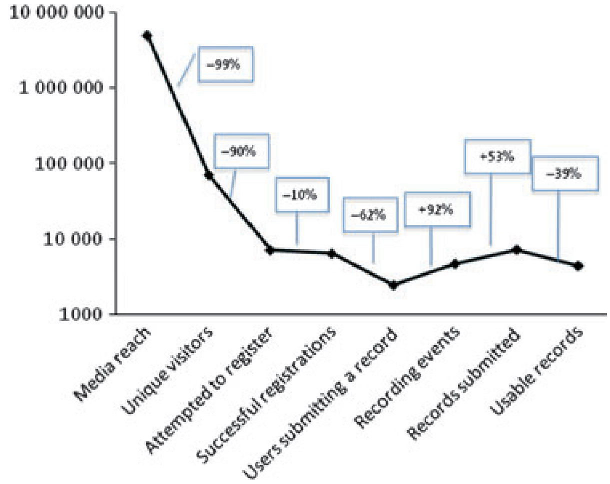

Fig. 3. Numbers of people reached by the Evolution MegaLab through broadcast and print media in the UK (5 million) and the numbers then visiting the website (all countries) and proceeding through successive stages to the submission of data records (note the log scale). The per cent loss (or gain) between stages is shown.

Evolution' in which students used the Evolution MegaLab as a part of the course assessment. In 2009, 1672 students were registered on the course, although only a minority contributed new data.

Looking at the UK experience in more detail illustrates the stages by which volunteer recruitment translated into the number of usable records received. From the circulation and viewing figures for the newspapers, radio stations and TV channels that carried news of the project, we estimate that the publicity campaign in the UK reached at least 5 million people (Fig. 3). Fewer than 1% of these visited the project website (data collected using Google Analytics) and of these only about 10% of those that visited registered. About 10% of those initiating the registration process failed to complete it.

Registration was required to upload data, but not to view results or download materials. Fewer than half the registered users (38%) submitted any data (Fig. 3). This was compensated for by users who recorded data on several occasions and from multiple populations. Rigorous cleaning of the data reduced the number of usable records to about 60% of the number submitted.

DATA QUALITY

Of the users registered on the Evolution MegaLab website, only 20% (1319) participated in the quiz and many of these did not submit data. For this reason, it was not possible to use individual quiz results as weights in our data analysis as we had originally intended. However, informative statistics were obtained from the quiz that we were able to use to decide which data were likely to be especially error prone and which could probably be relied upon. Question 1, distinguishing *Cepaea* from other snails, was answered correctly by 62% of users at the first attempt. We, therefore, looked especially carefully at records in which the morph ratios reported were not characteristic of *Cepaea*. Monomorphic populations of banded browns, for example, are practically unknown in *Cepaea*, and we discarded such records as likely to be caused by confusion with the common garden snail, *Cornu aspersum*. Suspect records were particularly common in small samples, so in the data cleaning process we removed samples containing fewer than 10 snails.

Question 2 asked users to distinguish between juvenile and adult *Cepaea*, and only a third got this right at the first attempt. We concluded from this that many juvenile *C. nemoralis*, in which the characteristic dark lip has not yet formed, had probably been erroneously identified in the field as being *C. hortensis* which has a white lip when mature. Question 3 showed that 84% of users could correctly distinguish at the first attempt between adults of the two species, showing that unlike those of *C. hortensis*, positive field identifications of *C. nemoralis* were likely to be correct. For this reason, we performed our first analysis of the results of the Evolution MegaLab exclusively on the latter species (Silvertown *et al.* 2011).

Yellow was the shell colour most accurately identified in the quiz, with 94% of users identifying a yellow shell correctly at the first attempt. Pink and brown shells were often confused with each other, although not with yellow, and therefore, we chose the frequency of yellow for analysis of shell colour. Over 95% of users correctly identified shell banding and band numbers at the first attempt, so these traits were also used in the analysis.

Cleaning the data set prior to analysis took many weeks. It is an essential step in data preparation and can potentially introduce bias, so we checked the resulting dataset against patterns generated from professionally collected data in our historical records (Silvertown *et al.* 2011). Removing unrecognized characters that were introduced by the use of the different character sets in 14 languages was unexpectedly time-consuming because it could not be automated. We identified more than 150 samples that were recorded in obviously wrong locations such as the ocean and contacted every such user via collaborators to ask them to check and correct their records. Very few users actually did so, so most of these records had to be removed.

Discussion

The huge effort and considerable cost (about £250 000 or more than £30/population sampled, the majority spent on staff costs) involved the Evolution MegaLab paid off in terms of both our scientific and public outreach objectives. Even after rigorous data cleaning, we obtained nearly 3000 new records on polymorphism in *C. nemoralis*, equivalent to a sample size that compared with our historical data set had previously required decades of professional effort to acquire. These records have given us an unparalleled picture of evolution in a model organism that has been studied by geneticists for nearly a century. They also set a new benchmark against which future studies can analyse evolutionary change. For the purposes of statistical analysis, we combined the historical and Evolution MegaLab data sets, giving us a sample size of just under 10 000 populations. In this analysis, which is reported in full elsewhere (Silvertown *et al.* 2011), we found no evidence of a general increase in the frequency of the yellow morph, thus unequivocally rejecting our initial hypothesis that climatic warming would cause an increase in the frequency of the morph with the highest albedo. We are confident that this conclusion is robust because the new, combined data set detected a cline in the frequency of yellow across the European continent that had been reported before (Jones, Leith, & Rawlings 1977), but not in as much detail as was revealed in our data (Fig. 4). This provides a degree of external validation for our data on the frequency of yellow.

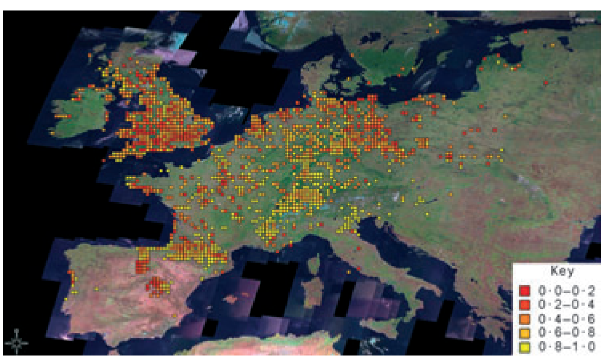

Fig. 4. The frequency of the yellow morph of *Cepaea nemoralis* across all modern and historic population samples averaged in quarter degree squares of latitude and longitude. From (Silvertown *et al.* 2011).

We set out with the intention that the public would help us re-sample the locations where past records had been made, but in the event, the geographical distribution of historical and Evolution MegaLab records were quite different (Fig. 2). Geneticists have tended to record in rural locations, while the public tended to record in more urban environments. With the benefit of hindsight, it ought to have been obvious that this would happen because the great majority of the European population live and study in cities. This is a factor to consider in planning future projects (Fink *et al.* 2010). There were also regional differences between the distribution of historical and modern samples caused by variation in the effort expended in publicising the Evolution MegaLab in different countries (Fig. 2). The unplanned difference in the distribution of samples over time presented difficulties for our analysis that we dealt with in our statistical models. However, as the results showed that there had been no change in the frequency of yellow over time, we were able to combine the historical and modern data sets, and the geographic differences between them became an unexpected asset because it gave us more comprehensive coverage of Europe than either data set on its own would have done (Fig. 4).

The analysis also produced two other unanticipated results. We detected a decrease in unbanded morphs and an increase in mid-banded as a proportion of banded, neither of which change was consistent with the expected evolutionary effects of climatic warming (Silvertown *et al.* 2011). Once we had found these changes, we looked for the same trends in our historic data set and found that the increase in mid-banded was present there too, thus proving that this unexpected result was not simply an artefact of sampling in the Evolution MegaLab. At the present time, we have no clear explanation for these evolutionary trends, although there may have been changes in predation pressure and habitat over time that influenced selection on banding and crypsis. The predation hypothesis we advanced in the Evolution MegaLab project has not yet been tested against the data we collected. However, in the context of the present study, one conclusion is so far clear – citizen scientists have helped reveal a puzzle that professional scientists have been oblivious to for decades, and citizen science through the Evolution MegaLab may well be the best way to investigate it further.

We believe that the success of the Evolution MegaLab was owing to a combination of factors, many of which ought to be relevant to other citizen science projects. First, we (i) had a valid scientific question that (ii) caught the imagination of the public and which (iii) they could help to answer. It is easy to have an idea that satisfies one or two of these requirements, but much harder to find one that satisfies all three of them. Second, we took advantage of a major, year-long event – Darwin year, 2009 – that gave us repeated publicity opportunities. It is much easier to get collaborators, journalists, teachers and potential funders to listen to your pitch if it is topical or, even better, prospective. Good advance planning paid off. Third, we used our funding and the time available to us through forward planning to produce materials that were carefully crafted for each of our many target audiences, from schoolchildren to undergraduates, and in most of the relevant European languages. The website was the most important of these resources, and this was tested and modified so that it was made as user-friendly as possible well before project launch. Fourth, we gave participants full, immediate feedback on their results. This is essential for motivating participants (Droege 2007). Finally, we did not attempt this project alone. We cast the net as wide as we could in drawing in collaborating scientists from our own and other institutions, and assistance from teachers' organizations, museums, journalists and broadcasters and every resource available to us at our home institution.

Naturally, there are things we could have done better. If we had asked participants to upload a digital photograph of their snail samples to the website, validating these would have been much easier and we would probably have lost fewer samples in the process of data cleaning. Figure 3, showing how small a fraction of the public that we reached with our publicity actually participated in the Evolution MegaLab, was a surprise. We draw the conclusion from this graph that the more one can focus publicity on participants who have already made a journey along a portion of this curve, perhaps by participating in a similar project previously, the more efficient recruitment will be. Another lesson we might draw is that there is now a potential community of Evolution MegaLab users with whom we should continue to engage. If we were planning the Evolution MegaLab now, we would use social networking websites such as Facebook, Twitter and Flickr for outreach and publicity, and we would produce an app for smartphones.

The Evolution MegaLab was purpose built, which enabled us to customize the website exactly to our requirements. This is probably still the best, perhaps the only way to build a site as complex as the Evolution MegaLab that functions in 14 languages, but there are off-the-peg options available now that did not exist when we began, such as EpiCollect for smartphones (Aanensen *et al.* 2009). There are more and more software building blocks available for gathering data from the public, processing it and displaying results, and these can be used to produce a site more quickly and cheaply. An open source customizable tool that is specifically designed for building biological surveys is Indicia (http://code.google.com/p/indicia), while Google's fusion tables will readily display the contents of data files on a web page in various graphical formats including maps.

From its inception, the Evolution MegaLab was conceived as a project in which science and education would both benefit. The measure of the success of the latter is in the very wide participation in the project in 2009 and the fact that the site continued to be used, even after we stopped promoting it publically. In 2010, an additional 1455 records were submitted. The majority of these were from Britain, but new records were also submitted from Spain, Germany, Austria, Switzerland, Ireland, The Netherlands, Estonia, France, Hungary, Italy, Poland and Portugal. The Evolution MegaLab continues to be used in schools where its multilingual interface has even been used in language teaching. It has also inspired others to use a citizen science approach in their research.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Video S1. EML Quiz.

Video S2. EML Data entry.

Video S3. EML Data maps.

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