OPEN ACCESS Freely available online

CourseSource

Teaching Tools and Strategies

Graphical Organizers as Course Road Maps: Using a geologic timescale in a history of life course

Matt Davis*

Department of Geology and Geophysics, Yale University, CT

Abstract

Both major and non-major biology students lack understanding of important evolutionary events, how they are spaced in time, and how they relate back to the earth system. Graphical organizers like concept maps and timescales are popular tools that are proven to effectively increase college students' conceptual understanding. By emphasizing biological events on a graphical organizer made from the geologic timescale, students gain a much needed theoretical framework for organizing and conceptualizing Deep Time. This article includes a new handout of the geologic timescale created specifically for introductory biology or History of Life type courses. The handout is useful both as a standalone activity and a road map for an entire course. Although it is highly adaptable, the geologic timescale is best used (both by students and instructors) as an organizational framework for all stages of History of Life courses from planning, lecturing and reviewing, to formative and summative testing. The timescale is a clear, visual index of student's knowledge about key evolutionary events and leads to greater student metacognition of conceptual linkages in the History of Life.

Citation: Davis, M. 2015. Graphical Organizers as Course Road Maps: Using a geologic timescale in a history of life course. *CourseSource*. https://doi.org/10.24918/cs.2015.4

Editor: Robin Wright, University of Minnesota

Received: 10/19/2014; **Accepted:** 11/19/2014; **Published:** 4/28/2015

Copyright: © 2015 Davis. This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.

Conflict of Interest and Funding Statement: The author is unaware of any conflict of interest. No external funding was involved in creation of this material.

Materials and Supplemental Materials: Figure 1: The DeepTimeScale, Figure 2: Example of notes taken on a student's DeepTimeScale, Table 1: Example of questions at various Bloom's levels of understanding that can be used with the DeepTimeScale, Supplemental File S1. Graphical Organizers-Complete DeepTimeScale handout and Supplemental File S2. Graphical Organizers-DeepTimeScale handout with spaces for students to fill in names

***Correspondence to:** Yale University, PO Box 208109, New Haven, CT 06520. E-mail: matthew.davis@yale.edu

INTRODUCTION

Despite repeated calls to focus more attention, at all levels of biology and geology education, on the rich macroevolutionary narratives found in the fossil record, studies continue to show that college students have a poor grasp of important biological and geological events in Earth's history (1-5). The History of Life course, which covers how life evolved from singled celled ancestors to complex multicellular modern organisms, frequently takes the form of a semester long introductory paleontology or geology course or is covered briefly in one or two lectures in more general evolution courses. Regardless of whether the topic is treated in one lecture or as a standalone course, professors usually teach the History of Life by tracing a progression of key evolutionary moments through Deep Time (e.g. first eukaryotic cells, first land animals, first mammals, etc.). Although this topical progression seems logical, anecdotal and experimental evidence shows that most college students, including those with strong biology backgrounds, struggle to arrange key evolutionary events in either relative order or on an absolute timescale (1,4,5). Part of this difficulty was recognized by Darwin (6) who blamed it on humans lack of conceptual framework for extremely long timespans. Conceptualizing any large number is hard (1,4,5,7,8) but the durations of time involved with the History of Life are so vast that they are many magnitudes longer than any possible anchoring reference frame that could occur in a normal human lifespan (4). Thus, most undergraduate students lack an appropriate conceptual framework for understanding the History of Life (1,4,5). The geologic timescale provides a theoretical framework for mentally and physically organizing key concepts in the History of Life that could be used to great effect by both instructors and students as a graphical organizer during course planning, lectures, note taking, active learning exercises, exam reviews, and assessments.

The formal geologic timescale, created in the 1800's (9) and continually refined to this day, (10) delineates major evolutionary and geological events in the history of the earth. It is not an arbitrary arrangement of dates and funny sounding units. Although most History of Life classes follow the geologic timescale as a logical system of organization, the timescale itself and the contingency and interrelatedness of geological and evolutionary events are not emphasized enough. Premade timescales currently available to instructors are not adequate for assisting undergraduates in their study. For example, the official timescales provided for free by the International Commission on Stratigraphy (11) and the Geological Society of America (12) are excellent references for professional geologists or paleontologists but they were not

designed for use in introductory classes. They are expensive to print because they are in color, contain a large amount of unnecessary information, and chop up the complete extent of the timescale into multiple columns with different scale bars so that 1 cm of length does not equal the same amount of time at all points on the page. Using multiple scales is understandable but it greatly confuses students who struggle to understand the amount of time elapsed between periods and the nestedness of geological units (e.g. eons subsume eras and eras subsume periods). Furthermore, these types of timescales are meant to be stand-alone reference charts, not graphical organizers for students with space to write down notes. As a result, they are separate from a student's normal note taking activity and relegated to a forgotten pocket in a folder or a crammed end page of a textbook.

Graphical organizers like timescales, concept maps or matrices, and flowcharts are popular pedagogical tools used at all levels of education (13). Multiple studies have shown that they are effective at increasing conceptual understanding and subject matter appreciation in college students (13-17) but whether they are most useful when presented before material (16), with material (13), immediately after material (18), or after a long delay (19) is still the subject of active research. Graphical organizers are thought to facilitate conceptual learning because they transform complicated textual information into easily digestible visual arrangements. This computational efficiency allows students to find and absorb information faster and is thought to free up the auditory region of the brain to better process verbal data from a lecturer (1,4,5,7,8,13,15) although a recent study (18) questions this assumption. Graphic organizers, like any tool, are most effective though when accompanied by detailed instruction and practice so that students can create and use them on their own (1,4,5,7,8,13,15,17).

DESIGNING A BETTER TIME SCALE

Because I saw that typical timescale handouts were not helping students, I created a new timescale handout, the DeepTimeScale. This graphical organizer is based on the dates and terminology found in Walker and Geissman (20) and applies the latest research on graphical organizers, which attempts to minimize most of the problems found in ready made timescales discussed above (Figure 1, see page 3).

There are pros and cons to having a timescale drawn completely at scale. Many events, including human evolution and the Pleistocene glaciations, are squished into a very small space. One option is a logarithmic scale, which has the advantage of balancing out the long stretches of early life with the quick burst of events in the recent. And though students may mentally recognize temporal magnitudes on a logarithmic scale, (4) I find that most have a hard time placing events correctly on a logarithmic axis. Also, graphically deemphasizing the Precambrian (about ~88% of Earth history) belies the major evolutionary steps and diversification taken by bacteria, archeans, and eukaryotes during this interval (3). Because students of all ages are much better at conceptualizing relative versus absolute time, a timescale that covers the entire range of Earth history on a linear scale should be easier to understand (1,4,5,7,8,13,15,17). Adding an extra timescale that covers just the Phanerozoic is a good compromise that allows students to see the entire history of earth at one constant reference scale while recognizing that most material covered will be from the Ediacaran period on.

The tabloid size of my DeepTimeScale handout stretches out the timescale so it can be viewed in one continuous line without chopping periods into different, disconnected blocks but the handout is not so large that it is ungainly. It can easily be folded or even printed out to the standard 8.5" by 11" size to better fit on small lecture desks. To simplify the DeepTimeScale and make it as generalizable as possible, no isotope curves, paleomagnetic polarities, or plate tectonics reconstructions are included, although these are certainly important features that instructors or students may wish to add to their copy of the handout. As much blank space as possible is included in the DeepTimeScale so that students can add in their own notes on important biological, climatic, and geomorphological events. The handout does contain extra dates and unit names that I am not concerned about students memorizing but these seem good to put in for reference and completeness and they can easily be deemphasized. Graphical organizers should mitigate the effects of seductive details (21) and by leaving the names of units blank that I want students to focus on, they know that only those names they write down are the important names that they need to memorize.

I find the DeepTimeScale handout is most effective when it is used as a road map for a semester long introductory course covering evolution or the history of the earth where students require no prerequisite knowledge. However, I have used the same timescale handout for an in class activity for an interdisciplinary graduate level geology course and I think the DeepTimeScale is adaptable enough that it could be used without modification for a wide range of students and experience levels as both an in class handout or as a take home worksheet.

USING THE DeepTimeScale EFFECTIVELY

Although some professors may find graphical organizers like the DeepTimeScale restrictive as a course framework (14), instructors of full semester classes dealing with the history of life should integrate the geologic timescale in all aspects of their course.

Before Teaching the Course

History of Life style courses tend to follow a similar organization: moving from the beginning of earth history to the present day. Within this organization, different instructors may focus on different aspects like phylogeny, taphonomy, or major climatic events. The DeepTimeScale is simple and flexible enough that it can be used by any instructor regardless of his or her focus. It is good practice to constantly refer back to the DeepTimeScale when planning out syllabi and lecture topics. As much as possible, list your lecture dates and topics right on the timescale to see how the course is flowing. Some segments of the timescale will not be covered evenly or even at all during class. The first 3,500 million years might take one or two lectures whereas the last 1 million years could be stretched over two or three lectures covering human evolution, the Pleistocene extinction, and modern global warming. This kind of uneven temporal coverage is certainly not wrong and is even to be encouraged, but plotting lectures along the DeepTimeScale crystallizes the instructor's own metacognition and helps align course material and assessments with learning goals. Posting this "timescale syllabus" online and referring back to it at the beginning and end of each lecture should help students' metacognition regarding the progression of the course and the connections from one day's material to

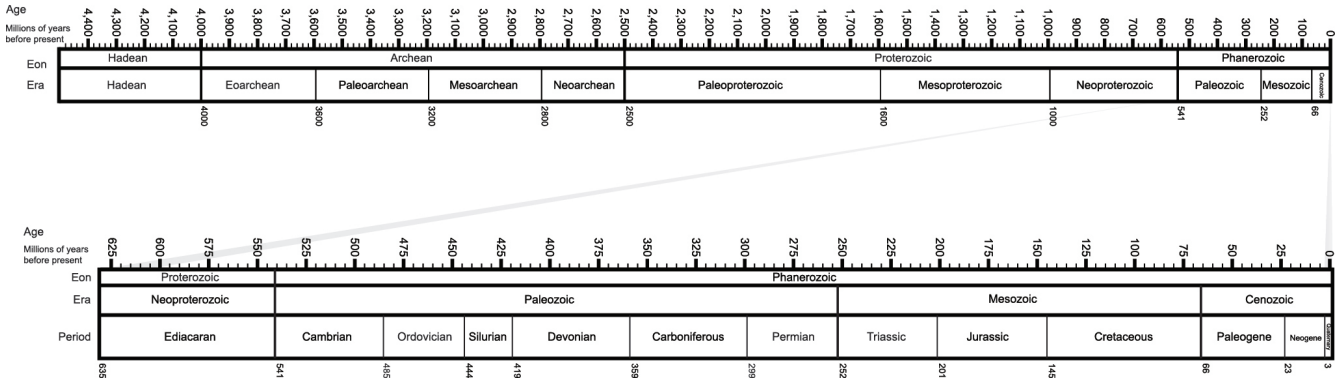

Figure 1. The DeepTimeScale, a simple geologic timescale designed for use in note taking by students in introductory History of Life or biology/evolution courses. The upper scale covers the entire history of the Earth and the lower scale magnifies just the last ~630 million years of the Phanerozoic eon and Ediacaran period.

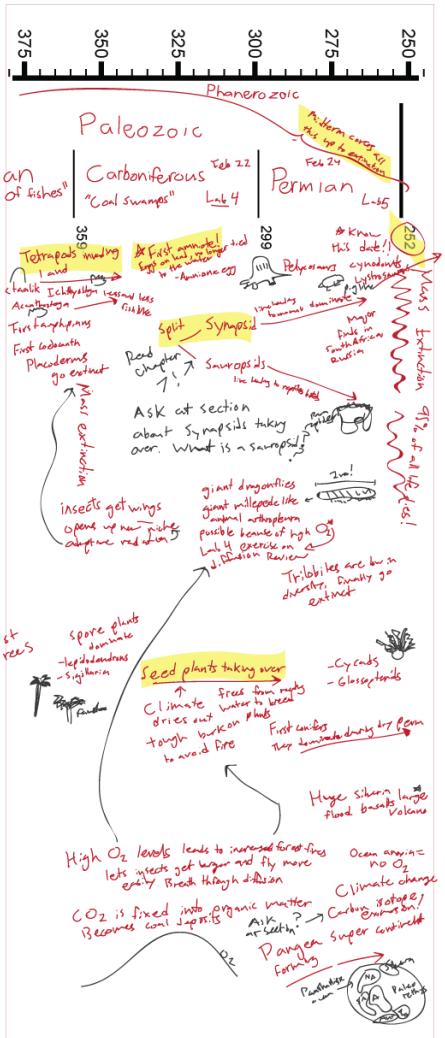

Figure 2. An example of how a student might fill in a portion of his or her timescale after lecture.

another's. I have had students complain that they studied the end Permian extinction for hours only to find it was not mentioned on the midterm. Having the syllabus clearly listed on the DeepTimeScale focuses both the instructor and the students on what material should be covered in class, homework, and during examinations.

The First Class

Print out the DeepTimeScale on 11" by 17" tabloid size paper and give each student a copy. It is a great idea to talk about the timescale at the same time you are going over the syllabus and course expectations. You can point out what periods or concepts major exams cover and how the lectures/labs are distributed throughout geological time as well as actual semester time. I've also tried to point out how successful students should use the DeepTimeScale to study and measure their own knowledge. Tell students:

You should bring the DeepTimeScale to every class and lab and keep it handy when you study. Use the DeepTimeScale to organize your notes and write as much as you can in the space provided. Use this to keep track of your own knowledge. By the end of the course, this page should be full and covered in notes and drawings. If you have gaps on your DeepTimeScale you should reflect on whether they are gaps in your knowledge. The History of Life is a story. It flows in a coherent way where events and organisms at one time set up events and organisms at a later stage. If you can sit in front of a blank piece of paper and reproduce this timescale from memory and use this natural flow to think backward and forward through time, you will be well positioned to get an A.

Subsequent Classes

At the beginning and end of each class, indicate where on the DeepTimeScale the material for that day will focus. This helps orient students to the main concepts of that session and situate them in the progression of the course and geologic time. This reorientation is just as valuable an exercise if the main topic of the day is a survey subject like modes of fossilization or a discussion of adaptive radiations throughout time. This keys in students that whatever being discussed does not belong to just one moment in time but that it is a pattern that they expect throughout Deep Time.

When asking questions in class or mentioning important fossil sites, it is helpful to direct students to the relevant point on the DeepTimeScale. Not all material or questions need to directly address a specific point on the timescale but the flow of geologic time and interrelatedness of events and organisms should be a constant guide for the course. The DeepTimeScale is a useful part of many different activities and questions at various levels of higher thinking (See Table 1, on page 5, for some example prompts at various Bloom's levels). The gradual filling in of the DeepTimeScale will serve as a formative self-assessment of relevant knowledge for students. Of course, the handout is too small to contain all relevant material and notes that a student needs but it should serve as a good index for important topics that can be referenced back to notebooks, lectures, activities, and textbook pages. Figure 2 (on page 3) provides an example of what a student's notes after class might look like.

Review

When students are reviewing for major summative assessments like the final exam, the instructor should hand out two more copies of the DeepTimeScale. For students who ask for suggestions on how and what to review, I recommend going through their notes and synthesizing their knowledge onto a clean version of the DeepTimeScale. The simple act of reorganizing and reevaluating things dashed off quickly in lecture with notes from readings or labs can be very beneficial. I then tell them that when you think you have completed your initial review, take a blank timescale and with friends (or alone), try to fill in as much as possible from memory. Try not to rely on rote memorization but instead use the logical connections and contingencies of events and organisms to guide you. Now compare the timescale notes you made from memory to your comprehensive notes. Where were there big mistakes or omissions? Focus the rest of your reviewing on those places.

Summative Assessment

Beginning students are often very nervous during final exams and may need some stepping stones to get to higher level assessments. The DeepTimeScale can be printed out on 8.5" by 11" paper and included as the first question of the exam. Students should fill in the names of important eons, eras, periods, and epochs. This helps them when they are confused or stumped on later questions as they can reconstruct the course along the familiar lines of the geologic timescale.

FURTHER STEPS

Using the DeepTimeScale as the road map for an introductory History of Life class gives students who lack backgrounds in evolution and geology a theoretical framework to organize their thoughts and notes on the course and increases their metacognition. Students have told me that the material does not seem complicated, it is just not familiar to them and they don't know how to arrange it in their heads or properly gage their own mastery of the subject matter. This timescale handout guides students into an effective and logical organization for the course. The DeepTimeScale is provided as a pdf in the supplemental material in both complete and unfilled versions (Supplemental Files S1,S2) so it can be enlarged or shrunk to any desired size. It is easily edited in a vector graphics program like Adobe Illustrator if an instructor wants to add or remove labels or details. Examine how students are using their DeepTimeScales and ask them what changes they would make if they were to design them. They will probably have useful edits to make on the timescale for future classes. Students may even want to devise their own timescales with added information on fossil locations or isotope curves at TimeScale Creator.

As mentioned before, the DeepTimeScale is probably best used throughout a semester long class but it can be easily used either at full size or printed out in letter size for a single activity on major evolutionary events in other introductory biology or evolution classes. Some websites that have good lists of important evolutionary events can be found at the Kentucky Geological Survey and The University of California Museum of Paleontology. Where students would normally write down a few key evolutionary events (first cells, dinosaurs go extinct, first mammals, etc.) on a table or list in their notebooks, they can now write down these events in the appropriate spots on the geologic timescale and get a sense for the time that passes between major events. (Note that the DeepTimeScale can be oriented vertically or horizontally depending on how the student wants to write down information). The same types of

Table 1: Graphical Organizers-Example of questions at various Bloom's levels of understanding that can be used with the DeepTimeScale

Bloom's Level	Example Question	Suggested Use
Knowledge	How many million years ago did the Cenozoic begin?	Pre class reading assessment
Comprehension	Draw one herbivorous and one carnivorous dinosaur from the Jurassic on your timeline. Compare and contrast the morphological features that allow us to make this dietary distinction.	In class activity/homework question
Application	Use a ruler to figure out the scale of the upper and lower geologic timescales printed on this sheet? How many years are there in 1 mm? How long would 100 years be in SI units for each timescale? Draw a scale bar for each timescale on your handout. Use http://htwins.net/scale2/ to find something that is approximately the width of one year for each timescale.	Homework question/quantitative reasoning group activity
Analysis	Shady Sam is trying to sell several fossils to your museum: A Cambrian trilobite fossilized in amber, a T-rex leg frozen in permafrost, and an early primate from Messel. State which fossils you would recommend buying (if any) and provide reasons why or why not.	Exam question/homework question/in class clicker question
Synthesis	Construct a plausible scenario of what would have happened to the long term evolution of arthropods and vertebrates if plants had not colonized land until the Devonian.	Medium length answer quiz question
Evaluation	Some geologists have proposed adding a new epoch known as the Anthropocene to highlight human environmental manipulation. Given what you know about how biological and geological factors differed between the various epochs in the Cenozoic, do you think a new epoch is warranted? Explain why or why not and when you think this new epoch should begin if it were created. What kind of index fossils or geologic features would mark this epoch for paleontologists of the far future?	Final exam essay question/homework essay question/group project prompt

Davis, M. 2015. Graphical Organizers as Course Road Maps: Using a geologic timescale in a history of life course. *CourceSource*.

questions and activities used for a semester long History of Life course can be used in one class period but it is advisable to stick to lower Bloom's level questions as there will not be time for students to gain a very rich understanding of the material.

Unfortunately, most studies only examine graphic organizers used in conjunction with short segments of text or one lecture. There is little research on graphic organizers that cover a whole course (14). However, it is easy to see how such teaching tools could be valuable road maps to many different subject areas. A history course could have one large map or timeline that covers the whole semester. A biochemistry course could have a cell diagram where students would fill in reactions where they occur in the cell. An osteology course might have a detailed diagram of the whole skeleton with dates of labs covering each region and a diversity of life or comparative anatomy class could have one large phylogeny where all organisms and traits studied could be illustrated. Using a graphical organizer as a course road map aligns teachers, students, and material to key course concepts while providing a strong physical and mental framework for students to organize knowledge.

SUPPLEMENTAL MATERIALS

- **Supplemental File S1.** Graphical Organizers-Complete DeepTimeScale handout: A pdf of a completed DeepTimeScale that should printed out in tabloid (11″ by 17″) or letter (8.5″ by 11″) paper. It can be edited in any vector based graphics program.
- **Supplemental File S2.** Graphical Organizers-DeepTimeScale handout with spaces for students to fill in names: A pdf of an unfilled DeepTimeScale with important unit names removed. It should be printed out or edited as Figure S1.

Acknowledgments

This article was conceived and written during the very helpful and exciting CourseSource summer writing workshop held at the University of Minnesota in 2014.

REFERENCES

1. Catley KM, Novick LR. 2009. Digging deep: Exploring college students' knowledge of macroevolutionary time. J. Res. Sci. Teach. 46:311-332.
2. Trend RD. 2001. Deep time framework: A preliminary study of UK primary teachers' conceptions of geological time and perceptions of geoscience. J. Res. Sci. Teach. 38:191-221.
3. Zook D. 1995. Confronting the evolution education abyss. J. Res. Sci. Teach. 32:1111-1120.
4. Lee H-S, Liu OL, Price CA, Kendall ALM. 2010. College students' temporal-magnitude recognition ability associated with durations of scientific changes. J. Res. Sci. Teach. 48:317-335.
5. Libarkin JC, Anderson SW, Dahl J, Beilfuss M, Boone W, Kurdziel JP. 2005. Qualitative analysis of college students' ideas about the Earth: Interviews and open-ended questionnaires. Journal of Geoscience Education 53:17-26.
6. Darwin C. 1859. On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life, 1st ed. John Murray, London.
7. Tretter TR, Jones MG, Minogue J. 2006. Accuracy of scale conceptions in science: mental maneuverings across many orders of spatial magnitude. J. Res. Sci. Teach. 43:1061-1085.
8. Jones MG, Taylor AR. 2009. Developing a sense of scale: Looking backward. J. Res. Sci. Teach. 46:460-475.
9. Boggs S Jr. 2001. Principles of Sedimentology and Stratigraphy, 3rd ed. Prentice Hall.
10. Knoll AH, Walter MR, Narbonne GM, Christie-Blick N. 2004. A new period for the geologic time scale. Science 305:621-622.
11. Cohen KM, Finney SC, Gibbard PL, Fan JX. 2013. The ICS International Chronostratigraphic Chart. Episodes 36:199-204.
12. Walker JD, Geissman JW, Bowring SA, Babcock LE. 2012. Geologic Time Scale v. 4.0. The Geological Society of America.
13. Vekiri I. 2002. What is the value of graphical displays in learning? Educational Psychology Review 14:261-312.
14. Torres MO, Espa?a RCN, Orleans AV. 2014. Integrating graphic organizers in facilitating learning chemistry. International Journal of Educational Studies 1:1-8.
15. Robinson DH, Kiewra KA. 1995. Visual argument: graphic organizers are superior to outlines in improving learning from text. Journal of Education Psychology 87:455-467.
16. Robinson DH, Corliss SB, Bush AM, Bera SJ, Tomberlin T. 2003. Optimal presentation of graphic organizers and text: a case for large bites? Education Tech Research Dev 51:25-41.
17. Spiegel GF, Barufaldi JP. 1994. The effects of a combination of text structure awareness and graphic postorganizers on recall and retention of science knowledge. J. Res. Sci. Teach. 31:913-932.
18. Shaw S, Nihalani P, Mayrath M, Robinson DH. 2012. Graphic organizers or graphic overviews? Presentation order effects with computer-based text. Education Tech Research Dev 60:807-820.
19. Bera SJ, Robinson DH. 2004. Exploring the boundary conditions of the delay hypothesis with adjunct displays. Journal of Educational Psychology 96:381-388.
20. Walker JD, Geissman JW. 2009. Geologic Time Scale www.geosociety.org. Geological Society of America.
21. Rowland-Bryant E, Skinner CH, Skinner AL, Saudargas R, Robinson DH, Kirk ER. Investigating the interaction of graphic organizers and seductive details: can a graphic organizer mitigate the seductive-details effect? Research in the Schools 16:29-40.