

Teaching with Electronic Chalk

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The advent of tablet PC's, i.e. laptops equipped with a special handheld digitizer pen for freehand writing on the laptop screen (Figure 1), has made possible a new mode of teaching, using "electronic chalk": hook up your laptop to a beamer, write your lecture on the laptop screen instead of the blackboard, save it afterwards and make it available to your students on the internet. Or, even better, prepare "gap-filled lecture notes", with gaps strategically placed to focus attention on the key steps of an argument or derivation, post them on the internet a day before lecture (for students to print out and bring along), fill in the gaps during lecture by digitizer pen on laptop screen (expecting the audience to do the same on their printed copies), and post the final version on the internet too (for those that prefer not to take notes at all). This combines the advantages of an electronic format (internet compatibility, ease of recycling, colours) with the virtues of blackboard teaching (flexibility, symbol-for-symbol explanation of key points, audience participation through taking notes). Encouraged by enthusiastic student feedback and a growing number of enquiries from intrigued colleagues that information on this new teaching tool might be of wider interest, these notes report my experiences with electronic chalk during three semesters of teaching undergraduate physics courses, and conclude with some tips and tricks for making it work smoothly.



Figure 1: A tablet PC is a regular laptop, but additionally equipped with a special handheld digitizer pen and a screen that can be swivelled 180 degrees and folded screen-side up to serve as electronic notepad for freehand writing. (Shown here: a ThinkPad X41 Tablet PC; I currently use an ACER TravelMate C300). Under Microsoft Windows, it allows freehand writing in several types of documents, including Word, Powerpoint, Windows-Journal (ideal for lecturing) and Adobe-products. (The digitizer pen does not work under Linux.)

What I am about to describe will not be of interest to lecturers blessed with the ability to fluently cover blackboards with neatly written, well-arranged formulas and text, while allowing the audience sufficient time to simultaneously take notes and digest what they are being told. Alas, many of us do not belong to this select circle of blackboard maestros: I, for example, have a poor blackboard handwriting and an incurable tendency towards speeding as time runs out towards lecture's end. Switching from the blackboard to writing on transparencies instead (scanning and distributing them via internet afterwards) only worsens my tendency towards speeding, since I write faster on transparencies than the blackboard. Thus, I decided to explore electronic alternatives, such as laptop plus beamer.

The idea of using laptops for teaching is, of course, not new, and seems to have received a boost from the increased use of Microsoft's PowerPoint program as the medium of choice for scientific talks (the comments below apply equally to LaTeX-lectures). The electronic format has numerous potential advantages:

- notes, in the form used during lecture, can be distributed as paper copies or in the internet;
- blackboard scribbles are replaced by colourful printed text;

- complex graphical material can be scanned or cut-and-pasted from books and journals;
- supplementary material not explicitly discussed in lecture can be included nevertheless;
- once prepared, lecture notes are easily recycled or updated for future use.

Moreover, one might expect that by having to write less themselves during lecture, students in principle will have more time to think about the content of the lecture.

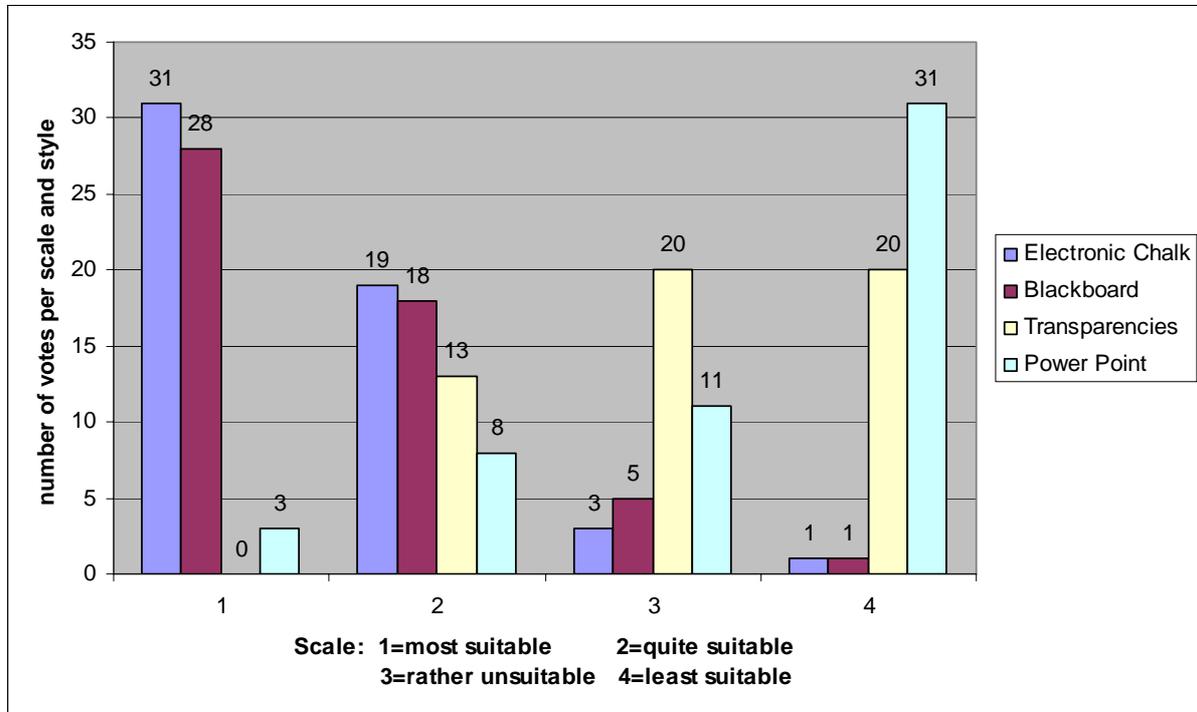


Figure 2: Results of an informal anonymous poll comparing different lecturing styles, taken on December 23, 2004, among 52 students attending my third-year Introductory Quantum Mechanics course at the Ludwig-Maximilians-University in Munich. Poll question: "Which lecturing style do you find most/least suitable for undergraduate physics courses, rated on a scale of 1 to 4?"

However, the countless hours invested in preparing a PowerPoint lecture series do not guarantee audience satisfaction. Quite the opposite, according to an informal poll (see Figure 2) among about 50 third-year students in my introductory quantum mechanics course, PowerPoint lectures are distinctly less popular than blackboard lectures. According to the students polled, the predominant complaints are:

- lecturers tend to speed when not forced to write down step for step what they are talking about, overwhelming their audience with page after page of insufficiently-explained details;
- average audience concentration levels are significantly lower (and noise levels higher!) if no one is taking notes. Indeed, while some students subscribe to the "write less, think more" hypothesis, about 50% declared that they concentrate better when actively taking notes;
- lack of flexibility when addressing questions from the audience or having to correct typos;
- simple explanatory sketches and diagrams tend to occur less often than in blackboard lectures (presumably since generating them electronically is more cumbersome);
- when confronted with a complete text (on screen or as handout), some students tend to read ahead rather than listen to the lecturer.

While the extent to which such issues are problematic or not strongly depends on the lecturer, the inherent *inflexibility* and *lack of audience participation (by not taking notes)* are undeniable disadvantages of the PowerPoint lecturing formats.

Enter electronic chalk: it combines all the benefits of an electronic format with the flexibility of blackboard teaching, in that it puts the (electronic) chalk back in your hand and frees you

from using only typeset material. The possibilities are legion. For example, if you don't typeset your notes and love the blackboard, you could continue to use it for lecturing, but prepare your notes in electronic freehand writing, allowing you to deposit them in the internet without using a scanner. Or, if you don't like chalk dust on your hands, you could write on the laptop screen instead of the blackboard while lecturing, exploiting the convenient editing possibilities offered by freehand writing (colours, erasing, insert-more-space, etc., see points 3 to 5 below), and save the result at the end, for internet distribution. Since this essentially corresponds to using "electronic transparencies", it is advisable (only) for lecturers with a natural tendency to write slowly and neatly.

The option which I have come to enjoy most is the one mentioned in the introduction. It involves posting "gap-filled lecture notes" [Figure 3 shows two examples] on the internet a day before lecture (for students to print out and bring along), filling in the gaps during lecture by digitizer pen on laptop screen (expecting the audience to do the same on their printed copies), and posting the final version on the internet too (for those that prefer not to take notes at all). By strategically placing gaps at all the essential steps of an argument or derivation, and using enough of them (my notes have about 30% gaps) the lecturer can avoid the speeding trap and force himself to explain – and the audience to listen to! – *all* essential points in detail.

The non-gaps will typically consist of material that is more supplementary in character, in the sense that it need not be discussed symbol for symbol, but is needed nevertheless if the lecture notes are to be self-contained and intelligible beyond the moment when the listener's short term memory is being overwritten by the next argument. Examples would be: explanatory phrases complementing crucial steps in calculations, intermediate but straightforward steps of tedious calculations, complicated diagrams, lengthy definitions, summaries of previous lectures or known results from other lectures or courses, section and chapter headers, page and equation numbers, cross references to other pages and equations, references to the literature, etc. I was surprised to discover how much of my notes consist of such supplementary material. Its immediate availability both on the laptop and beamer screens *and* in the audience's printed notes saves both lecturer and audience much time, which the lecturer can use for more leisurely explanations, and the audience for better digesting the latter, without the distraction of having to frantically copy from the blackboard for the mere sake of having a complete set of notes. In other words, much tedium can be avoided for both lecturer and audience by eliminating the blackboard from the information transfer process between lecturer and audience note pads, while the virtues of the blackboard style, namely flexibility, attention to essential details, and audience participation, are retained via filling in the gaps in the gap-filled notes.

In the abovementioned informal poll among my quantum mechanics students, taken in December 2004 while this new teaching method still was very much in its experimental phase (about 8 weeks after I started using it), electronic chalk turned out to be a notch more popular than blackboard lectures (see Figure 2), with lectures using transparencies or PowerPoint ranking far behind for reasons given above. The poll also asked students to describe what they liked/disliked about electronic chalk. The positive aspects can be summarized as follows: students liked the fact that

- the final version of the lecture notes is available in the internet, so that
- they can choose between taking notes or not (the ratio is roughly 50-50);
- they spend less time copying supplementary material than with blackboard lectures, so that
- they are better able to concentrate on the essential steps as the gaps are being filled in;
- the essential steps are being developed symbol for symbol, "in real time";
- the use of colour makes the presentation easier to follow;

- the number of copying errors made by students is very much reduced, since they write less;
- typos in the gap-filled notes can be corrected on the fly as students spot them;
- pages and equations can be numbered and cross-referenced consistently.

Among the negative aspects mentioned by students were the following:

- notes not written entirely in one's own handwriting are more difficult to study from, and
- the success of electronic chalk strongly depends on the handwriting of the lecturer (remedy for both complaints: switch from longhand to typing for longer text passages – but I write all formulas by hand nevertheless, since most of them end up as gaps, anyway);
- a lingering tendency toward speeding remains (remedy: increase the number of gaps!);
- some students stated that they digest the material better if they write down all of it themselves (but this is a minority – most students prefer to just fill in gaps);
- discussing material spread over several pages is cumbersome (remedy: use two beamers!);
- too perfect lecture notes reduce the incentive to read textbooks(!).

Today, about a year and two undergraduate courses later, I would like to extend the above lists as follows, from the point of view of the lecturer, starting with some more pros:

- questions and comments from the audience are more frequent than with blackboard lectures;
- the amount of material covered per lecture did not increase compared to when I taught the same course using transparencies in the past, but the amount of time spent on explanations and discussions did;
- the ease of editing afforded by the freehand writing tools (see point 3 below) is a great incentive for improving the layout of the notes;
- while the preparation time per lecture (6 to 10 hours) is significantly longer than for a blackboard lecture (but probably comparable to a PowerPoint lecture), a significant amount of this time is spent optimizing the layout of the material to be presented – as a result, the final version typically looks a lot better (in terms of neatness, transparent organisation and use of colour) than the average blackboard layout, and, for that matter, the average set of student notes (which often are such a mess that one shudders at the thought of someone actually studying from them);
- filling in well-chosen gaps in a well-prepared gap-filled lecture is a lot of fun, and this fun seems to rub off on the audience.

However, there are some undeniable cons, too:

- the increased reliance on technology implies an increased vulnerability to technical problems (deficient beamer cable, students unable to print out notes before lecture due to crash of internet server, forgetting the digitizer pen at home, etc.);
- gap-filled notes do not foster learning the technique of independently taking good notes (remedy: students can learn this in courses taught by blackboard maestros, who will always stick to using blackboards!).

All in all, it will be a matter of personal style how you weigh the pros relative to the cons. In the end, no amount of technical gimmickry can outweigh the eternal cornerstones of good teaching, namely a sound grasp of the material, good preparation, clarity of presentation and enthusiasm. However, at least in my case, the latter three ingredients are boosted significantly by using electronic chalk!

Tips and Tricks

In case you are intrigued, here are 10 points of advice to help you get started. If what follows seems overwhelmingly cumbersome, rest assured: given some practice, the key steps can all be performed very quickly and efficiently – the amount of work is presumably less, or at worst, comparable to typesetting a lecture using PowerPoint or LaTeX.

1. Technical prerequisites: a beamer and a tablet PC (google for “tablet laptop”).
2. Lecture pen: To enable the audience to follow your explanations on the beamer screen without you using an additional pointing tool (e.g. a laser pointer), it is absolutely essential that it sees an image of your digitizer pen on the beamer screen while you write. Strangely, the standard tablet PC software package does not yet provide a corresponding pen imaging tool, but one can be obtained by downloading “lecture pen” free of charge from www.veridicus.com/tummy/programming/lecturepen. This brilliant little program, written by a benevolent hacker within three hours(!) after I posted a cry for help to a tablet PC newsgroup, creates an icon at the bottom of your desktop, clicking on which switches on or off the image of a fountain pen on the laptop screen, placed such that its tip follows the current position of the cursor (reminiscent of a pen’s shadow when writing on transparencies).
3. Freehand writing: For lecturing, I use the program Windows-Journal, which comes installed with tablet PCs. It offers wonderfully quick and comfortable freehand editing features, such as a “pen” for freehand writing and drawing and split-second changing of colours and line widths, a “textmarker” for high-lighting, an “eraser” with various line widths (including a very convenient erase-the-entire-line-you-touch feature), together with cut-and-paste, drag-and-drop and insert-more-space tools, which give you complete freedom in getting the notes to look like you want them, quickly (no need to wrestle with the formatting conventions of PowerPoint or LaTeX). Inserting typewritten text (insert, text) or graphical material (e.g. cut-and-pasting from a .pdf file) is likewise straightforward.
4. Colours: Beamer-compatible pen colours are black, blue, red, violet, dark orange and magenta (but not green!), with the pen line width set to “medium”. For high-lighting or putting boxes around equations using the “textmarker”, yellow and orange work well, with line width set to “thin”. It helps the audience to adopt some fixed colour conventions, such as black for text, page and equation numbers, blue for non-gap formulas, *red for all gap material* (since red jumps to the eye when taking notes), yellow for boxes around key formulas, etc. To change the colour of existing freehand writing, mark it, click on edit, freehand formatting, etc.
5. Faint guiding lines: can be switched on while preparing the notes and lecturing to help you write straight, but should be disabled before saving the result as a .pdf file (see point 9) for printing and posting to the internet, since when printed, they come out much darker than you’d expect. To switch them on or off, click on file, page setup page, style, set the line style to “defined by user”, and adjust the colours of horizontal and vertical lines to either light grey or white. You can similarly switch on lines to define a left margin (a broad one, reserved for short text passages and free from formulas, helps to structure the layout of your notes).
6. A template with settings that I found to work well for lecturing is available at www.theorie.physik.uni-muenchen.de/~vondelft/echalk/echalktemplate.jnt
7. Numbering equations and pages: needs to be done by hand, since Windows-Journal is not a typesetting program. A convenient scheme is to number pages by chapter (e.g. F1, F2, ... for

the chapter on Fields, R1, R2, ...for the chapter on Relativity, etc.), to number equations anew for each page, (1), (2), ... [to avoid having to renumber equations if you renumber pages], and to refer to equations from pages other than the current one by combining page and equation number, e.g. (F2.3). Equations designated to contain gaps can be numbered, too, by displaying their left-hand sides, or at least the = signs, as non-red non-gaps (this helps both lecturer and audience to judge how much space to use when filling in the gaps).

8. Adding and filling the gaps: Begin by preparing and saving the complete, final (gapless) version of your lecture notes, say notesA.jnt (Windows-Journal files have the ending .jnt). It is advisable to decide already at this stage what material is destined for gaps, writing it in red (see point 4). Create a printable version (see point 9) of notesA.jnt, say notesA.pdf, to be used as lecture notes for yourself in lecture to remind you what to write in the future gaps. If you use a second beamer (see point 10), create another printable version of notesA.jnt, say notesB.pdf, and copy it to a memory stick. Now add the gaps: save notesA.jnt under a new name, notesC.jnt, and erase all material destined to become gaps (everything in red); due to the power of the erase-the-entire-line-you-touch eraser, this typically takes just 5 minutes or so. Save the now gap-filled version notesC.jnt for archival purposes, create a printable version notesC.pdf to be posted on the internet as “pre-lecture version”, and save the gap-filled version again as notesD.jnt, which is what you will use in lecture. After filling in the gaps in the latter during lecture, save the result in printable form as notesD.pdf and post it on the internet too, as “post-lecture version”.

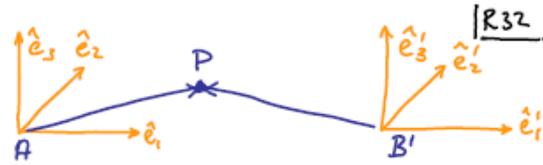
9. Printing: To print your notes or post them on the internet, create a .pdf version of your .jnt file. First switch off the faint guiding lines (see point 5), click on file, print, select the Adobe PDF or FreePDF XP printers, select landscape mode, and set the number of pages to be printed per sheet. For my own master set of lecture notes (notesA.pdf), I like a compact format of 4 pages per sheet; for the second beamer (notesB.pdf), you need 1 page per sheet; for the pre- and post-lecture gap-filled notes (notesC.pdf and notesD.pdf), students prefer 2 pages per sheet. The resulting .pdf files typically have sizes of 0.5 to 1.5 MB.

10. Second beamer: the luxury version of teaching with gap-filled notes uses two beamers, the second of which can be used to display previous pages of the lecture which might be relevant while filling in the current page's gaps (very convenient for lengthy derivations, or for big figures filling an entire page, but needed to elucidate a subsequent calculation). Ideally, you'd be lecturing in a hall with a permanently installed beamer, hook it up to your tablet PC and fill in the gaps in version notesC.jnt, while using a second, portable beamer and second (non-tablet) laptop to display the version (notesB.pdf) saved on your memory stick (see point 8).

Relativistic addition of velocities

Recall Lorentz transformation from page R20:

- ①: $t' = \gamma(t - \frac{vx}{c^2})$
- ②: $x' = \gamma(x - vt)$
- ③: $y' = y, z' = z$
- ④: $\gamma = 1/\sqrt{1 - v^2/c^2} > 1$
- ①': $t = \gamma(t' + \frac{vx'}{c^2})$
- ②': $x = \gamma(x' + vt')$



Velocity of point P:
according to Alice:

$$\vec{u} = (u_x, u_y, u_z), \quad u_x = \quad, \quad u_y = \quad, \quad u_z = \quad \quad (1)$$

according to Bob':

$$\vec{u}' = (u'_x, u'_y, u'_z), \quad u'_x = \quad, \quad u'_y = \quad, \quad u'_z = \quad \quad (2)$$

u'_x expressed
through u_x, v, c :

$$u'_x \stackrel{(2)}{=} \frac{dx'}{dt'} \stackrel{\text{chain rule}}{=} \quad = \quad = \quad \quad (3)$$

$$= \gamma(u_x - v) \gamma(1 + \frac{v}{c^2} u'_x) \quad (4)$$

Solve for u'_x :
(check algebra at home!)

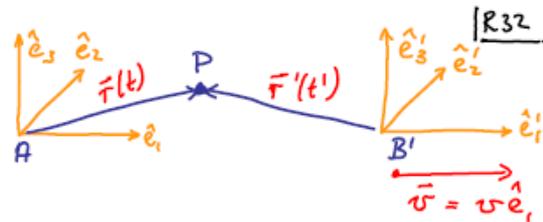
$$u'_x \left[1 - \gamma^2 \frac{v}{c^2} (u_x - v) \right] = \gamma^2 (u_x - v) \quad (5)$$

$$u'_x = \frac{(u_x - v)}{\frac{1}{\gamma^2} + \frac{v^2}{c^2} - \frac{u_x v}{c^2}} \stackrel{(4)}{=} \frac{u_x - v}{1 - \frac{u_x v}{c^2}} \quad (6)$$

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- ②': $x = \gamma(x' + vt')$



Velocity of point P:
according to Alice:

$$\vec{u} = (u_x, u_y, u_z), \quad u_x = \frac{dx}{dt}, \quad u_y = \frac{dy}{dt}, \quad u_z = \frac{dz}{dt} \quad (1)$$

according to Bob':

$$\vec{u}' = (u'_x, u'_y, u'_z), \quad u'_x = \frac{dx'}{dt'}, \quad u'_y = \frac{dy'}{dt'}, \quad u'_z = \frac{dz'}{dt'} \quad (2)$$

u'_x expressed
through u_x, v, c :

$$u'_x \stackrel{(2)}{=} \frac{dx'}{dt'} \stackrel{\text{chain rule}}{=} \frac{dx'}{dt} \frac{dt}{dt'} = \gamma \left(\frac{dx}{dt} - v \right) \gamma \left(1 + \frac{v}{c^2} \frac{dx}{dt'} \right) \quad (3)$$

$$= \gamma(u_x - v) \gamma(1 + \frac{v}{c^2} u'_x) \quad (4)$$

Solve for u'_x :
(check algebra at home!)

$$u'_x \left[1 - \gamma^2 \frac{v}{c^2} (u_x - v) \right] = \gamma^2 (u_x - v) \quad (5)$$

$$\frac{1}{\gamma^2} \stackrel{(4)}{=} 1 - v^2/c^2$$

$$u'_x = \frac{(u_x - v)}{\frac{1}{\gamma^2} + \frac{v^2}{c^2} - \frac{u_x v}{c^2}} \stackrel{(4)}{=} \frac{u_x - v}{1 - \frac{u_x v}{c^2}} = u'_x \quad (6)$$

Figure 3a: Example of gap-filled notes, before (above) and after (below) filling in the gaps. Examples of non-gap material which need not be spelled out symbol for symbol during lecture are: the Lorentz transformation formulas and the figure (both known from a previous lecture), the definitions of velocities in the frames of A and B (easy to grasp), the algebraic manipulations needed to solve for u'_x (tedious, to be checked at home), and the equation numbers (needed later). Gaps are used only for the really essential parts of the calculation.

Twin Paradox: (From Mermin, "It's about time: Understanding Einstein's Relativity", Chapter 10) R35
 Bob flies to a distant planet and back, returning to find himself two hours younger than his twin sister Alice. A and B don't find this strange, if they watch each other's clocks throughout. (Study photon tracks!)
 Suppose clock readings change each full hour, emitting a flash of light, seen by other twin somewhat later:

According to Alice:
 In her first (proper) hours, she sees B's clocks flashing times, so

$$\frac{1 \text{ B-hour}}{1 \text{ proper hour}} =$$

In her last (proper) hours, she sees B's clocks flashing times, so

$$\frac{1 \text{ B-hour}}{1 \text{ proper hour}} =$$

For total travel time shown on Bob's watches, Alice finds:

$$\begin{aligned} & (\text{proper hours})_x \left(\frac{\text{B-hour}}{\text{proper hour}} \right) \\ & (\text{proper hours})_x \left(\frac{\text{B-hour}}{\text{proper hour}} \right) \\ & = \text{B-hours} \end{aligned}$$



According to Bob':
 In his first (proper) hours, he sees A's clocks flashing times, so

$$\frac{1 \text{ A-hour}}{1 \text{ proper hour}} =$$

In his last (proper) hours, he sees A's clocks flashing times, so

$$\frac{1 \text{ A-hour}}{1 \text{ proper hour}} =$$

For total travel time shown on Alice's watches, Bob finds:

$$\begin{aligned} & (\text{proper hours})_x \left(\frac{\text{A-hour}}{\text{proper hour}} \right) \\ & (\text{proper hours})_x \left(\frac{\text{A-hour}}{\text{proper hour}} \right) \\ & = \text{A-hours} \end{aligned}$$

Twin Paradox: (From Mermin, "It's about time: Understanding Einstein's Relativity", Chapter 10) R35
 Bob flies to a distant planet and back, returning to find himself two hours younger than his twin sister Alice. A and B don't find this strange, if they watch each other's clocks throughout. (Study photon tracks!)
 Suppose clock readings change each full hour, emitting a flash of light, seen by other twin somewhat later:

According to Alice:
 In her first 8 (proper) hours, she sees B's clocks flashing 4 times, so

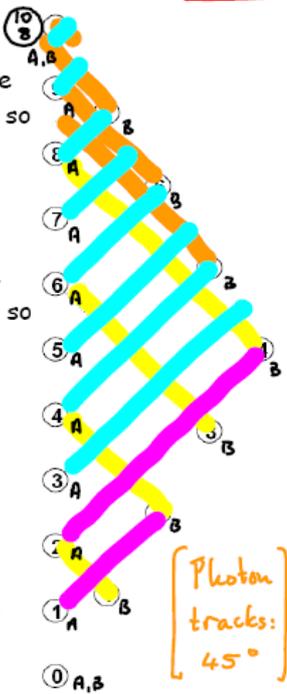
$$\frac{1 \text{ B-hour}}{1 \text{ proper hour}} = \frac{4}{8} = \frac{1}{2}$$

In her last 2 (proper) hours, she sees B's clocks flashing 4 times, so

$$\frac{1 \text{ B-hour}}{1 \text{ proper hour}} = \frac{4}{2} = 2$$

For total travel time shown on Bob's watches, Alice finds:

$$\begin{aligned} & (8 \text{ proper hours})_x \left(\frac{1}{2} \frac{\text{B-hour}}{\text{proper hour}} \right) \\ & (2 \text{ proper hours})_x \left(2 \frac{\text{B-hour}}{\text{proper hour}} \right) \\ & = 8 \text{ B-hours} \end{aligned}$$



According to Bob':
 In his first 4 (proper) hours, he sees A's clocks flashing 2 times,

$$\frac{1 \text{ A-hour}}{1 \text{ proper hour}} = \frac{2}{4} = \frac{1}{2}$$

In his last 4 (proper) hours, he sees A's clocks flashing 8 times,

$$\text{so } \frac{1 \text{ A-hour}}{1 \text{ proper hour}} = \frac{8}{4} = 2$$

For total travel time shown on Alice's watches, Bob finds:

$$\begin{aligned} & (4 \text{ proper hours})_x \left(\frac{1}{2} \frac{\text{A-hour}}{\text{proper hour}} \right) \\ & (4 \text{ proper hours})_x \left(2 \frac{\text{A-hour}}{\text{proper hour}} \right) \\ & = 10 \text{ A-hours} \end{aligned}$$

Figure 3b: Example of gap-filled notes, before (above) and after (below) filling in the gaps. Examples of non-gap material which need not be spelled out symbol for symbol during lecture are: The reference to the literature, a short statement of the problem, explanatory phrases elucidating the calculation, and the backbone of the rather complex figure. Gaps are used only for the key steps of the argument, and colours to conveniently distinguish various cases.