Blackboards, PowerPoint, and Tablet PCs in the Classroom

Jason Harlow, David M. Harrison
and Ruxandra Serbanescu

Department of Physics
University of Toronto

December 2005 (last rev: May 26, 2008)

Introduction

Research into eye movements of subjects who are reading provides a window into the reader's cognitive processes. Here we use some conclusions of that research to guide a discussion of the delivery of visual information in the classroom.

We will briefly review some of the highlights of the research into eye movements that have particular relevance to how people learn from complex written materials. Next we shall discuss some general principles of the traditional "lecture," followed by three real-world cases from undergraduate physics courses at the University of Toronto. The variation of a laptop computer called a Tablet PC will be part of all three cases; a brief discussion of Tablet PC's appears in Appendix A.

How We Process Visual Information

The visual field can be divided into three regions: the *foveal*, *parafoveal*, and *peripheral*. Visual acuity is best in the foveal region, is somewhat poorer in the parafovea, and is even worse in the peripheral region.

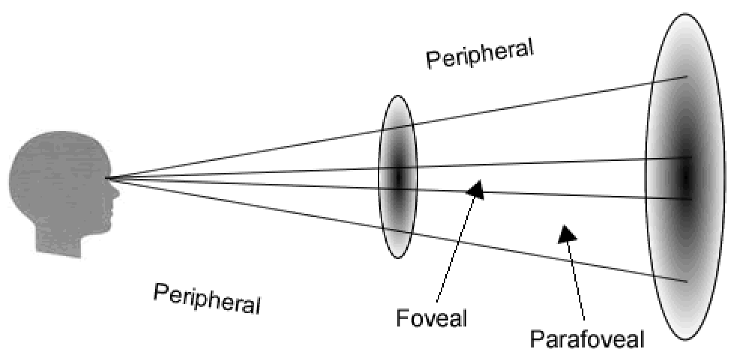


Figure 1: Three visual fields

From the centre of our gaze, the foveal region extends about 2 degrees. The parafoveal extends about 5 degrees from the centre, while the peripheral region extends nearly 90 degrees.

As can be seen in the figure, the *area* corresponding to a region depends on how far the object is away from us. In fact, the area varies as the square of the distance. Thus the area divided by the square of the distance is constant, and is called the *solid angle*.[1] It is conventionally measured in units of *steradians* (sr). The foveal region has a 3.8 millisteradian (msr) solid angle, the foveal plus parafoveal regions comprise 24 msr, and the foveal, parafoveal plus peripheral regions have a 2π sr solid angle.

Over the past 25 years there has been an explosion in studies using measurements of eye movements to investigate cognitive properties. A fairly recent review is Rayner, 1998. Here we will only skim the surface of this vast field.

When we read, our eyes remain relatively still during *fixations* which typically last for 200-300 ms. The fixations locate the material being read in the foveal region. The gaze then jumps at high speed to another fixation, in a movement called a *saccade*. The text seen in the parafoveal and sometimes peripheral regions usually determines where the next fixation will occur.

About 10-15% of saccades are *regressions*, which are movements opposite to the direction of the reading. Regressive saccades longer than 10 letter spaces, or to a previous line, occur because the reader did not understand the text. As the complexity of the text increases the number of regressive saccades increases.

Although we do saccades all the time without being conscious of them, we also consciously go back further than a typical regressive saccade to re-read sections of difficult text. So reading involves both conscious and unconscious re-reading of text, and the more complex the contents the more this is necessary. However, if the text that needs to be re-read is no longer anywhere in the visual field then getting to it is more difficult and, instead of regressive saccades, requires bringing the need to our consciousness.

It is interesting to note that very large regressive saccades involve a spatial memory of where the text is, and does not involve either a parafoveal or peripheral preview. [Inhoff, 2005] For text that is not in our visual field, we also often have a conscious spatial memory such as "it is on a left-facing page, about two-thirds of the way down."

A similar spatial memory seems to be involved when we look away from text that we are reading: the location of the text most recently read informs us where to direct our gaze when we look back at the material.

General Issues in the Classroom

In a traditional classroom there is a blackboard, usually with multiple panels. The professor writes on a panel, and then goes on to other panels leaving the original in front of the students until space runs out and earlier panels are erased. Watching a class being held in such a room shows that the students are continually glancing back at the earlier material. In the language previously used, the students are doing *regressive saccades* or

[1] Technically, the solid angle is not the plane area but the area of a section of a sphere. As used in this paper the difference is totally negligible.

consciously re-reading, just as they do when reading their textbook. This is totally expected: the students do not yet have the course content in their long-term memory. [Harrison, 2002] Of course, the students are also glancing back and forth between the blackboard panels and the professor.

Although now considered "low tech," in the early 19th century a blackboard was on the leading edge of pedagogy. Samuel J. May, an abolitionist and education reformer, wrote in 1855 about his first exposure to this technology: [May, 1855]

> "… in the winter of 1813 & '14 , during my first College vacations, I attended a mathematical school kept in Boston by the Rev. Francis Xavier Brosius . . . On entering his room, we were struck at the appearance of an ample Black Board suspended on the wall, with lumps of chalk on a ledge below, and cloths hanging at either side. I had never heard of such a thing before. There it was—forty-two years ago—that I first saw what now I trust is considered indispensable in every school—the Black Board—and there that I first witnessed the process of analytical and inductive teaching."

One nice technique in a classroom with a multiple-panel blackboard is to "chunk" the lectures into coherent pieces. Each chunk is designed so that it begins on the upper-left of the first blackboard panel and finishes by just filling all the board space. [Redish, 2003, pg. 127] After completion, one may go over the entire argument again so that the students have a context and can see the whole presentation at once.

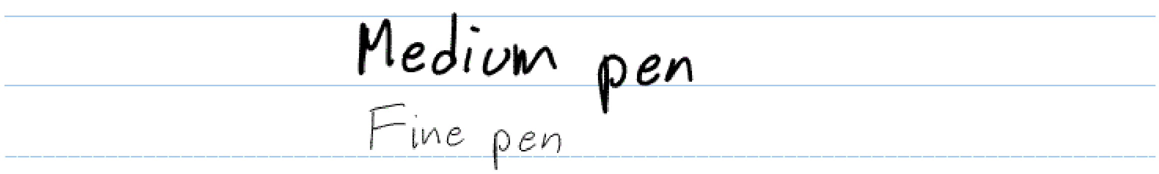
Now consider a typical PowerPoint presentation. Once a slide is replaced by the next one, the original is no longer available for the students to see. Thus it is impossible for them to saccade to the earlier material. Providing hardcopy of the slides in advance of class ameliorates this somewhat by giving the students something to refer back to, although not in as natural a fashion as glancing at another panel of the blackboard.

Table 1 shows the results of measuring the visual field of the blackboard and projection screens of two classrooms, the University's 2000-seat auditorium, and a piece of paper. The classrooms that were measured are among the best at the University; there are many classrooms that are worse than these. Details about the rooms appear in Appendix B. Unless otherwise indicated, the angles are from the centre to the edge; edge to edge angles are approximately double the values shown. Also shown is the *Relative Area*, which is the width times the height (in degrees) normalized by the area of a piece of paper held 32 cm from the eye. With the exception of the auditorium, which does not have a blackboard, the visual field of the blackboard is in all cases larger than any of the screens in the room. And none come close to the visual field of a piece of paper. Figure 2 at the end of this document summarises.

Although the three rooms described in Table 1 and Appendix B are used for classroom instruction, there is a *research* laboratory at the Ontario Institute for Studies in Education called the *Knowledge Innovation & Technology Lab* (KITL). [OISE, 2006]. This room can be configured in a number of ways, but features up to five simultaneous projectors, or four projectors and an electronic *Thunder* “flip chart”. Figure 3 shows the room configured using all five projectors. Appendix C describes the room further. The visual field of this room, when configured for five projectors, measured from the corner opposite the middle screen and using the same methodology as Table 1, is:

- Width (degrees) × Height (degrees): 82 × 11
- Solid Angle (msr): 1,200
- Relative to a piece of paper: 2.31

However visual fields are not the whole story. Below we discuss three cases of using a Tablet PC in place of a blackboard. One of these classes meets in a 2000-seat auditorium. The Tablet PC can write with a number of different “pen” types. Here is an example:



Although the “Fine pen” looks good on the screen of the Tablet PC and is almost certainly readable in this document, by the time it has gone through the projector and onto the main screen of the auditorium it is not readable to most of the class. Thus the medium pen is about the minimum that can be used. This constraint limits the amount of material that can be displayed on the screen.

For PowerPoint presentations there is an additional factor. The style imposed on most PowerPoint presentations by the software reduces the amount of information per slide; Tufte discusses this in more detail. [Tufte, 2003]

Thus, in addition to the visual field, the amount of information that can be contained within that field is also a factor. Thus below we will refer to the *visual/information field*.

Another issue involving classes based on either PowerPoint or pre-prepared overhead transparencies is that the material is “canned.” As a recent whitepaper at the University of Toronto stated:

> “Students make it clear that simply replacing the use of the blackboard by a PowerPoint presentation offers them the opportunity to sleep in the dark but that, even awake, they miss a key element in the learning process: observing a professor think in real time, as he or she develops material step by step.” [University of Toronto, 2004]

Finally, there is an unanswered question about the type of content and its relationship to the suitability of a particular method of presentation. Is the use of PowerPoint or overhead transparencies, both with canned content, more appropriate for a descriptive discipline, such as History or Biology, than an analytic one like Physics or Mathematics?

A 1,600-student first year course in Biology has been very successful, and the classes are 100% PowerPoint based.

In this regard, there are data that indicate that effective techniques of studying for tests vary depending on the type of content being tested. [Walker, 2003] In particular, for descriptive fact-based content, "pulling an all nighter" the night before a test can improve the grade. However, if the test requires analysis and synthesis, the lack of sleep and consequent decreased mental agility dramatically worsens student performance.

Case 1: A Huge First Year Course

A few years ago we were confronted with doing a 1,100-student first year class in physics for the life sciences, given as a single lecture section in a huge auditorium. The physical layout of the auditorium includes a central main and two smaller screens to the left and right of the stage; each screen has its own dedicated projector. Some photographs of the auditorium appear as Figures 4 and 5 at the end of this document.

For this situation, there are not really any good choices. Even if the room had a blackboard, we would have to write in *huge thick* letters for it to be visible from the back. Two things that DMH instituted for this course are:

1. The use of a Tablet PC projected onto the main screen. We develop the material in real time by writing on the Tablet. After class, the notes are made available to the students in pdf format.
2. When a major definition, figure, equation, etc. has been developed on the Tablet, after the development is complete a version is shown on the side screens. Thus, students can and do glance back at that content in a natural way. The material on the side screens persists for the students to see until we need to put something else on those screens.

Using this method requires a considerable increase in the time necessary to prepare each class.

We have been happy with student performance as measured by the normal tests and exams. In addition, student surveys have been positive about this methodology. In one survey we asked the students this question:

> The main content of the classes was delivered using the ***Journal*** program on a Tablet PC, with some ***PowerPoint*** slides and other information on the side screens. How effective was the use of the Tablet PC for your education?
>
> 1 2 3 4 5 6 7

The answer key is:

1. totally useless
4. neutral
7. an invaluable aid to my learning

65% of the class answered 5, 6, or 7. The mean of all answers was 4.96.

This huge course is divided into quarters with a different "lecturer" for each. A few years ago, three of the four lecturers used the technique described above, while the person doing the third quarter did not "buy in" to this and made the classes 100% PowerPoint-based. This individual did use a Tablet PC for these classes, so that material was added to the slides in "real time" using *digital ink*.

The students expressed a strong preference for the way the other three quarters of the course were done. However, students are sometimes resistant to change. Thus, even if the methodology of the third quarter were correct in principle, the fact that it followed two quarters using a different technique would have perhaps doomed it to failure.

Almost all students take notes during the class. However, we observe them glancing at the side screen much more often than at their notes, although both probably contain the same information. This may indicate that providing hardcopy of a PowerPoint presentation for students to refer to is not as good as providing an increased visual/information field at the front of the room.

Case 2: A 35-Student Second Year "Real" Physics Course

Earlier we quoted a University White Paper about the importance of developing material in real time in the classroom. However, there is more to it than just this. This year a 35-student second year physics course, held in the 100-seat Lecture Hall described in Table 1, began the year using conventional blackboard pedagogy. Complicated figures, etc. were presented on the side screen via PowerPoint.

This course is a serious offering in physics for the life sciences, given by RS. The students that take the course do so because they want to learn more "real" physics, and there are alternative courses for students who don't want to take this one.

Half way through the fall term a Tablet PC became available, and RS converted to using it on the Side Screen in place of the blackboard. The material continued to be developed in real time, plus the "bonus" that the material written on the Tablet was made available to the students after class.

Nonetheless, after a few weeks the lecturer noticed that the class was becoming less dynamic, and the questions during class were becoming much less frequent. The lecturer polled the students, and 16 of 26 students asked that the classes return to using the blackboard.

A couple of reasons spring to mind about why the students expressed this preference:

1. The visual/information field of the projected Tablet PC is much smaller than the 4-panel blackboard. This explanation is consistent with much of this paper.
2. When writing on a Tablet PC the lecturer is pretty well fixed in space, standing in front of the Tablet and writing. Using a blackboard requires more movement and energy. Expenditure of energy by the lecturer almost always increases the general level of energy and engagement in the students.

The students said that they learned more in the classes done on the blackboard, and some also mentioned the higher energy level in the room. They also said that the fact that the writing on a Tablet PC can be made available after class via the web might help their long-term learning, but thought it more important to more fully understand the material in class as it was being presented. Appendix D describes the student comments more fully.

We tried other methods of presenting visual material in the class. Then at the end of the term a paper survey asked students which method they preferred. The teaching methods and survey results are shown in Table 2. Over three-quarters of the registered students (27 of 35) responded to the survey, and the displayed uncertainties are statistical.

The methods listed in the table are in the order in which they were used in the classroom. As can be seen, the two methods based on the blackboard were the clear winners, and there is no sign in the survey results of a resistance to change. For the two blackboard methods, adding digital ink to the PowerPoint on the side screen was rated much higher than static PowerPoint by the students.

We did some experiments in this room. We wrote some material including a figure and equation on the blackboard, using standard-sized “lecture” letter sizes: upper-case letters were about 12 cm high. The blackboard was clean, and had not been erased. The material did not quite fill one of the four panels of the blackboard. We wrote the same materials on the Tablet projected onto the side screen using a fine pen and with the lights over the blackboard turned off; the screen was almost full. The two examples were equally legible from all locations. However, for the blackboard there were still three panels that were empty. Thus, the visual/information field was four times greater for the blackboard than for the Tablet PC. From the back row, a circle just circumscribing a 12 cm high upper-case **H** on the blackboard had a field of view of about 35 μsr.

Figures 6 and 7 at the end of this document are some photographs of this room. If you are reading this document online, the legibility looks very close to the photographs. In hardcopy, the legibility depends on the resolution of the printer and whether or not it is in color. Further photographic studies of the room are at http://www.physics.utoronto.ca/~jharlow/utfa06/classroom.htm.

Case 3: An 84-Student Second Year Liberal Arts Course

The course, new this year, is given in the 200-student Lecture Hall described in Table 1. It is titled "Physics of Everyday Life" and has 84 students, most in the humanities or social sciences. It is given by JH.

The course began the year using a Tablet PC projected onto the Main Screen. About half way through the first term a technical problem arose, and that one class was instead given using the blackboard. The lecturer has a lot of experience from previous courses in using a blackboard.

A couple of weeks later JH distributed an anonymous survey asking the students which format they preferred. About 30% of the class, 27 students, responded and had attended the class based on the blackboard. All but one student preferred the Tablet PC to the blackboard. Appendix E gives some of the student comments on this issue.

We did the same experiments that we discussed in Case 2 above. When we wrote material on the blackboard, we were shocked to discover that from the back row of the room the blackboard was nearly unreadable. This was due to the poor contrast and resolution of chalk on a blackboard more than the size of the writing. The Tablet PC with the medium pen projected onto the main screen was easily readable from the back row of the room. So in this case the increased visual field of the blackboard is not important, but the resolution is vital. Fourteen student comments in the survey summarised in Appendix E mention this in one way or another.

As mentioned, writing with larger letters on the blackboard did not improve this situation very much using a standard 1 cm diameter piece of chalk. The width of the strokes written with such a piece of chalk is about 4 mm.

We placed a whiteboard at the front of the room, and wrote on it the same content with the same size as on the blackboard. When we used the tip of the whiteboard marker, the width of the strokes was about the same as writing with a piece of chalk, and the visibility from the back of the room was the same or worse than the sample on the blackboard. However, the felt tip of the marker was beveled, and writing with the largest flat surface increased the stroke width to 6mm. This 2 mm increase produced a dramatic difference in readability: the content was easily readable from the back of the room. This is the same issue as using the *Medium pen* or *Thin pen* when projecting a Tablet PC in the 2000-seat auditorium that was discussed earlier.

Figures 8 and 9 at the end of this document are some photographs of this room. If you reading this document online or printed with a high resolution color printer, the legibility of the writing on the blackboard and the whiteboard really is this bad. Further photographic studies of the room are at http://www.physics.utoronto.ca/~jharlow/utfa06/classroom.htm.

Typographers have long known that higher resolution hardcopy is easier to read than lower resolution. The lower limit for professional typesetting is usually taken to be 1200 dpi, although for high-quality graphics 2500 dpi or better is required. [Bokor, 1998] Note that in a teaching context "easier to read" also means easier to understand. Thus if material on the blackboard is legible, if it is not easy to read it is not as effective.

Although we believe that legibility is the key issue here, there are possibly other factors too. Earlier we have discussed a possible interaction between the type of material of a course and effective methods of classroom presentation. It is possible that the "whiz bang" factors of a Tablet PC presentation are more important for these liberal arts students than for the more analytically oriented students of Case 2. In addition, for this Case the students were reacting negatively to a change in methodology; as already discussed students are sometimes resistant to change.

Conclusions

We have argued that allowing students to re-read visual materials with a glance is important to their understanding the visual information and meta-information being presented in the classroom. Given the actual layout of the typical "semi-smart" classroom, both at our institution and others, provided the room is not too large the greater visual field of the blackboard may make it the preferred medium. The actual technology, whether a Tablet PC or a PowerPoint presentation, can further constrain the material that can be in front of the students at one time.

Unanswered questions include how the subject of the course interacts with the importance of this conclusion. It is possible that for an analytic course such as physics issues of visual/information field are more important than descriptive courses such as biology or even liberal arts physics courses.

Adding digital ink to PowerPoint presentations, so that further development and emphasis occurs in real time in the classroom, can greatly increase the effectiveness of a class presentation using this technology.

For very large classrooms, the standard blackboard does not have sufficient resolution to be easily readable from the back of the room. One of us (DMH) has lectured in the 200-seat room discussed in Case 3 off and on for decades, and has only now discovered that the blackboard is largely illegible from the back row.

Somewhat arbitrarily, we designate the blackboard in the 100-seat classroom discussed in Case 2 as having the minimum acceptable visual field. Each of the 4 panels of this blackboard has physical dimensions of 2.2 m x 1.1 m, and is 9 m away from the back row. This corresponds to a solid angle of about 30 msr. A 12 cm high upper-case letter on this blackboard has a solid angle of 25 μsr measured from the back row. These values are roughly comparable to the results of a study of the minimum necessary field of view in the design of a "Virtual Auditorium" to support dialog-based distance learning. [Chen, 2001] This application involves subtle issues involving reading facial expressions and body language while still being able to view the virtual group as a whole, and confronts similar resolution issues to those involved in using a blackboard in a real classroom.

If the blackboard has a smaller field of view than the minimum, the resolution issues of writing with chalk on a semi-black surface makes it unacceptable. The maximum distance from the student to the blackboard should not exceed 9 or 10 m, although this number depends on factors such as:

- The lighting in the room.
- Whether the chalk is "dustless" or not.
- Whether or not the blackboard is clean, and how effective are the erasers.

Earlier we stated that for a constant angle of the visual field, the corresponding area of the field of view increases as the square of the distance; another consequence of this geometry is that for a constant sized area the angle of view decreases as the square of the distance. Thus exceeding the 9 or 10 m maximum student-blackboard distance decreases legibility very rapidly.

For these very large classrooms alternatives to the blackboard include a Tablet PC projected onto a reasonable sized screen, or a whiteboard provided a wide tip marker is used.

Given sufficient resources, one may imagine high-resolution "smartboards" with large visual fields being a wonderful alternative to the blackboard or whiteboard, but financial and technical constraints make that still just a dream for most of us.

Finally, when using a classroom for the first time it is important to check the readability of the presentation method from various locations in the room before the first class. There are classrooms that appear to be good but actually are not.

Additional Information

In April 2006 we presented much of the material to a conference of people at the University of Toronto particularly interested in education. This included asking the participants some questions about appropriate methods of delivery of visual information in the classroom. A pdf version of the PowerPoint presentation, including participant responses to the questions we asked, is available at:

http://faraday.physics.utoronto.ca/PVB/Harrison/BlackboardPptTablet/UTFAPresentation/BB_UTFAPresent_After.pdf

Acknowledgment

We thank Greg Vowles for a careful reading of this manuscript.

Appendix A: Tablet PCs

In its usual format, a Tablet PC is just a normal laptop except that the screen can be rotated to lie flat over the keyboard. In this mode, a *Journal* program acts like an electronic piece of paper. One may write on the screen of the Tablet with a special stylus, and the result can be projected onto a screen. There are a variety of pen sizes and colours. In addition, there are erasers, highlighters, and a selection tool that allows one to grab a previously written section and copy and paste it elsewhere. Images may be imported into the Journal. One may also convert handwriting to text, or insert text boxes. The contents of the Journal can be converted to formats such as pdf suitable for delivery via the web.

In addition, when a PowerPoint presentation is being displayed using a Tablet PC, “digital ink” allows one to write on a slide in real time. One may optionally save the slide with the digital ink.

Finally, for mathematical disciplines there is a program that can recognize hand-written mathematics, including calculus, and solve, graph or animate the expressions. [Xthink, 2005] This allows the actual solution of mathematical relations to be developed and solved in real time in front of the students.

Appendix B: Classroom Data for Case Studies

Here are some details about the rooms described in Table 1.

The 100-seat Lecture Hall is McLennan Labs room MP134. The blackboard has 4 panels, arranged in a 2 x 2 configuration; we measured the entire blackboard, not an individual panel. There are 2 Side Screens, and we measured the largest one. In addition, we measured the Main Screen. When lowered, this screen obscures just less than one-half of the left and right blackboard panels. The room has a permanent projector using the largest Side Screen; in order to use the Main Screen a portable projector must be brought into the room.

The 200-seat Lecture Hall is McLennan Labs room MP102. The blackboard is identical to the one in the 100-seat Lecture Hall. There are 2 Side Screens and we measured the largest one. In addition we measured the Main Screen. When lowered, this screen obscures about one-half of the left and right blackboard panels. In addition, from the back row the projector obscures some of the top of this screen. The room has a permanent projector using the Main Screen; in order to use one of the Side Screens a portable projector must be brought into the room.

The 2000-seat auditorium is Convocation Hall. In addition to measurements of the screens we measured the centre-to-centre distance from the Main Screen to one of the Side Screens.

The piece of paper is a standard 8 ½ x 11 inch one, and it was 32 cm from the eyes.

Appendix C: The KITL Research Facility

The *Knowledge Innovation & Technology Lab* at the Ontario Institute for Studies in Education is designed as a research tool for pedagogical studies. It can seat up to 30 people, and the furniture can be configured for a number of purposes. It features:

- Up to five projectors. Two of them project side-by-side on a wall, the third projects onto a screen in the corner, and the remaining two project side-by-side on the adjacent wall.
- *Thunder* electronic “flip chart”. This replaces the corner screen and. software enables previous charts to be displayed sequentially to the other four projectors.
- *Polycomm* video conferencing.
- Various capture systems, including *Breeze* and *Accordent*.

Appendix D: Comments of a Small Class That Preferred the Blackboard to the Tablet PC

Here is a summary by RS of some student reactions from Case 2, the “real” physics course:

- They could take a better advantage in understanding the concepts by having the two sides of the lecture presentation displayed at the same time: the four blackboard panels plus the PowerPoint on the screen.
- In the long run, the saved Journal notes could be useful, but having them doesn't replace the in-class learning which is better without the Tablet.
- The Journal displays very little at a time as compared to the blackboard; switching back and forth is "annoying.”
- In writing on the Tablet, the lecturer is more "static" which they did not like.

Appendix E: Comments of a Large Class That Preferred the Tablet PC to the Blackboard

Here are some student comments from Case 3, the liberal arts course, on the survey about preferred teaching format.

- Please do keep the Tablet PC, this is one of my favourite aspects about this course. I wish more professor used this method.
- Tablet is kind of slow, but the colour makes for clear diagrams.
- Tablet PC makes it easier, because you concentrate on what he is saying, instead of copying down the notes, since the notes are posted in the exact same way they were presented in class. (x 6)
- The online lecture notes should contain more detailed information than those in the lecture.
- Tablet PC saves time, no need to erase, easier to see, diagrams are clearer.

- Tablet PC is much clearer to see. (x 10)
- With the blackboards, not everything is easy to read, sometimes the view is blocked.
- Tablet PC is great because you can print the notes.
- Tablet PC seems more flexible for prof, better diagrams and different colours make the notes easier to read. Those of us in the front row don't have to inhale chalk, either.
- Tablet PC is better than normal overheads, and we can review online.
- Having the computer makes it easy to go on web and do online demos.
- The chalk board was distracting (noise and movement).
- Tablet PC puts bigger words on screen.

References

[Bokor, 1998] Gabe Bokor, "Translation and Typesetting," Translation Journal **1**(2), 1998. http://accurapid.com/journal/03type.htm

[Chen, 2001] Milton Chen, "Design of a Virtual Auditorium," Proceedings of ACM Multimedia Conference 9, 2001, http://graphics.stanford.edu/papers/virtual_auditorium/paper.pdf

[Harrison, 2002] David M. Harrison, "How Does the Delivery of Information Help Students to Learn?" 27th International Conference on Improving University Learning and Teaching, Vilnius Lithuania, July 2002, 275-280. Also at: http://www.upscale.utoronto.ca/PVB/Harrison/EncapsulatedLong.pdf

[Inhoff, 2005]. Inhoff, A.W. & Weger, U., "Memory for word location during reading: Eye movements to previously read words are spatially selective but not precise," Memory & Cognition, **33**, 2005, 447-461.

[May, 1855] Samuel J. May, American Journal of Education **28**, 1855, 28.

[OISE, 2006] "How is technology changing the way we build knowledge?" Available from http://www.oise.utoronto.ca/ec/academic_computing/kitl.php.

[Rayner, 1998]. Keith Rayner, "Eye Movements in Reading and Information Processing: 20 Years of Research," Psychological Bulletin **124**(3), 1998, 372-422.

[Redish, 2003] Edward F. Redish, **Teaching Physics with the Physics Suite** (Wiley, 2003).

[Tufte, 2003] Edward R. Tufte, **The Cognitive Style of PowerPoint** (Graphics Press, 2003). Available from http://www.edwardtufte.com/tufte/powerpoint.

[University of Toronto, 2004] **Stepping Up: 2004 – 2010**, Companion Paper 1, "Enabling teaching and learning and the student experience," available from http://www.provost.utoronto.ca/English/Companion-Paper-1---Enabling-teaching-and-learning-and-the-student-experience.html

[Walker, 2003] Matthew P. Walker, Tiffany Brakefield, J. Allan Hobson and Robert Stickgold, “Dissociable stages of human memory consolidation and reconsideration,” Nature **425**, 2003, 616-620.

[Xthink, 2005] The *MathJournal* program from http://xthink.com/

Table 1 – Some Visual Fields

	What	Width (degrees) x Height (degrees)	Solid Angle (msr)	Relative Area
100-seat Lecture Hall:	Blackboard: from the middle of the room	20 x 10	256	0.51
	Side Screen: from the middle of the room	10 square	124	0.26
	Main Screen: from the middle of the room	8 square	79	0.16
	Blackboard: from the back row	14 x 7	122	0.25
	Side Screen: from the back row	7 square	60	0.13
	Main Screen: from the back row	6 square	44	0.09
200-seat Lecture Hall	Blackboard: from the middle of the room	13 x 6	97	0.20
	Side Screen: from the middle of the room	4 square	20	0.04
	Main Screen: from the middle of the room	6 square	44	0.09
	Blackboard: from the back row	8 x 4	39	0.08
	Side Screen: from the back row	3 square	11	0.02
	Main Screen: from the back row	4 square	20	0.04
2000-seat Auditorium	Main Screen: from the middle of the first floor	14 x 10	176	0.36
	Side Screen: from the middle of the first floor	7 x 5	43	0.09
	Main Screen to Side Screen centre to centre: from the middle of the first floor	26 degrees	NA	NA
	Main Screen: from the back of the first balcony	7 x 5	43	0.09
	Side Screen: from the back of the first balcony	2 x 1.5	3.7	0.01
	Main Screen to Side Screen centre to centre: from the back of the first balcony	17 degrees	NA	NA
Sheet of paper		17 x 23	520	1

Table 2: Results of a Survey of Different Presentation Methods in a 2nd Year "Real" Physics Course

Method	Number of Classes	Rating (1 = terrible, 5 = excellent)
Blackboard plus static PowerPoint on the side screen.	15	Mean: 4.08 ± 0.16 Median: 4 Mode: 4,5
Tablet PC plus PowerPoint with digital ink, both on the side screen	9	Mean: 3.42 ± 0.21 Median: 3 Mode: 3
Blackboard plus PowerPoint with digital ink on the side screen	6	Mean: 4.58 ± 0.21 Median: 5 Mode: 5
PowerPoint with digital ink only on the side screen	5	Mean: 3.73 ± 0.21 Median: 4 Mode: 3

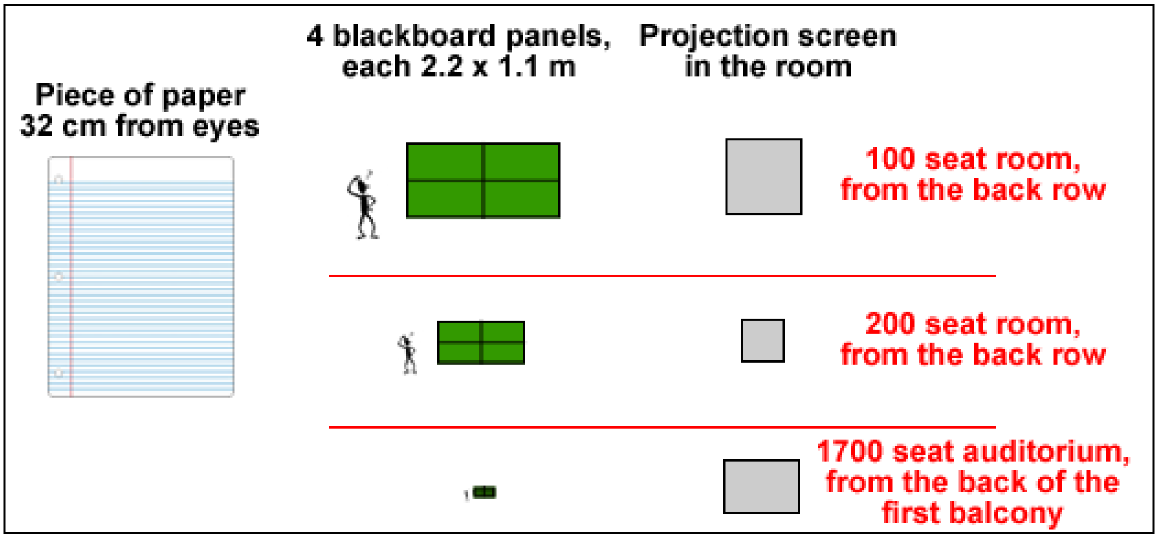


Figure 2: Summarising the visual field information of Table 1.
All figures are drawn to the same angular scale.

Figure 3. The *KITL* room. All five projectors are in use. The electronic flip chart is not in use, but can be seen to the right of the center screen.

.

Figure 4: the huge auditorium. Part of the main screen can be seen on the left and one of the side screens is near the center of the photograph. DMH is about to launch a nerf air rocket into the crowd as part of a discussion of projectile motion.

Figure 5: the students in the huge auditorium, taken from the side of the stage.

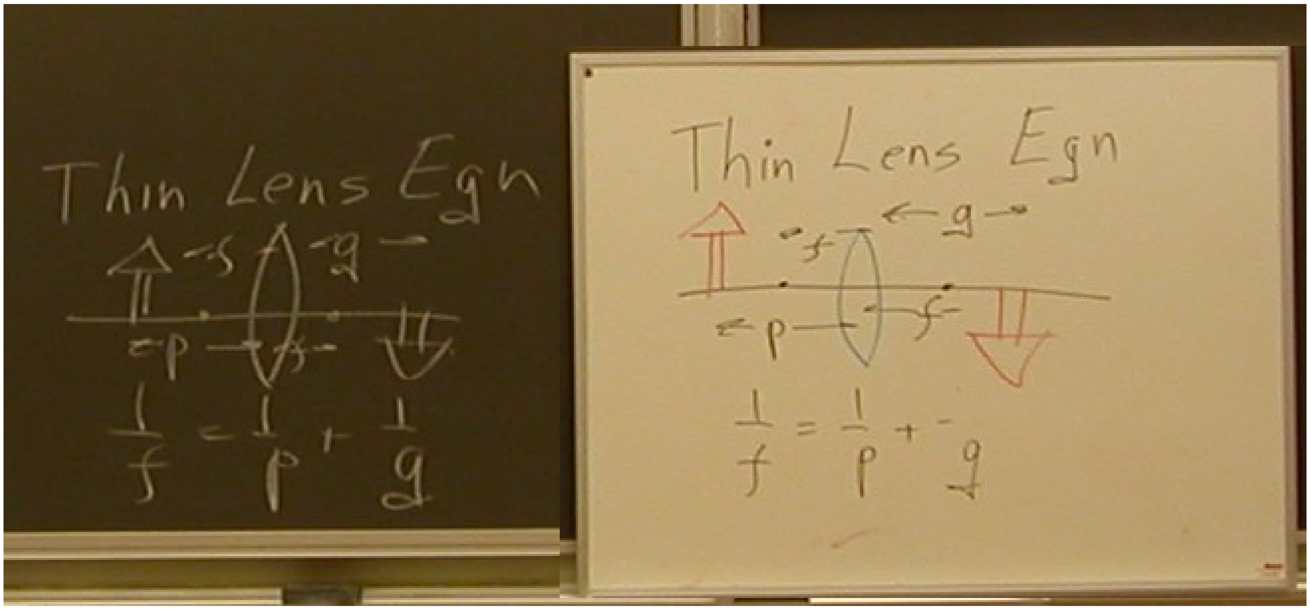


Figure 6: the 100-seat lecture hall, from the back row. On the left is the blackboard, on the right a whiteboard. All the lights are on. The photograph is cropped but not zoomed.

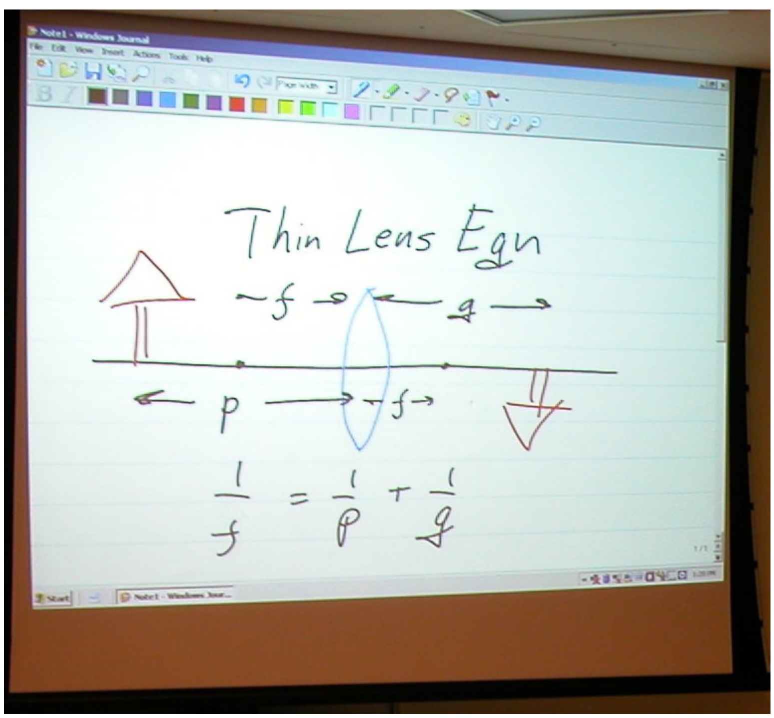


Figure 7: the 100-seat lecture hall, from the back row. The Tablet PC projected onto the side screen. The display fills the screen. The room lights are dimmed. The size of the photograph has been reduced by 50% in order to fit on the page.

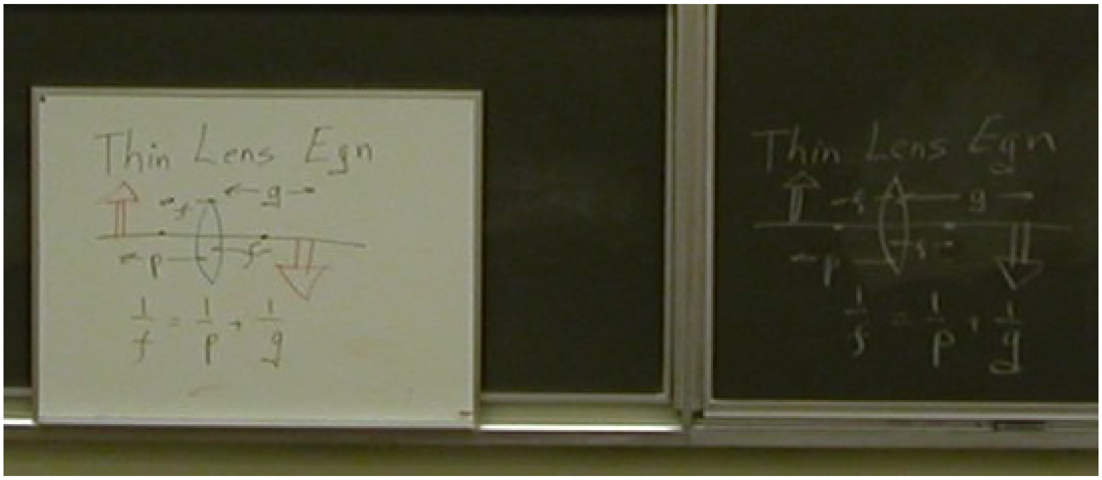


Figure 8: the 200-seat lecture hall, from the back row. On the left is a whiteboard; on the right is the blackboard. All lights are on. The whiteboard pen has a standard 4mm thick stroke. The photograph is not zoomed, but has been cropped.

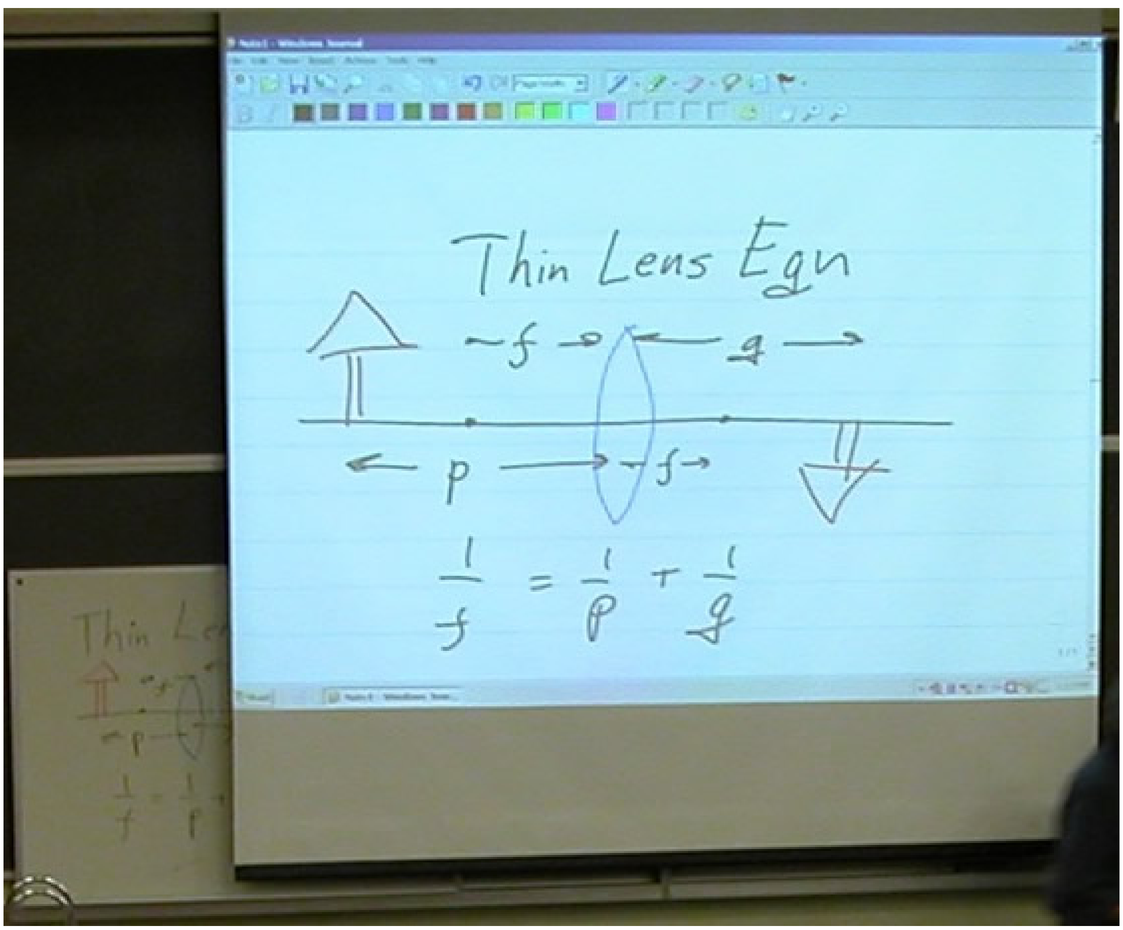


Figure 9: the 200-seat lecture hall from the back row. The Tablet PC with the medium pen, projected onto the main screen. The front two panels of lights are off. The photograph is not zoomed but has been cropped.