Using eye-trackers to study student attention in physical science classes

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Physics education researchers have had a strong impact on how professors teach physics and physical science courses. Faculty can find an instructional strategy to match their personal philosophies, yet how do students pay attention in those classes? There is the old belief that you have your students’ attention for the first 15 minutes of class but after that their attention declines. Researchers have studied student attention in the past but have not used an eye-tracker to truly capture what students look at during class. This study is the first to introduce eye-trackers to investigate student attention in a lecture or more accurately a large group instruction environment. I conducted this study in the fall and the spring semester of a physical science course. One student in each class wore an eye-tracker. I found that the first 15 minute adage is not necessarily true. Over the course of an entire class students have the ability to stay on-task fairly consistently.

Keywords: Eye-tracking, lecture, undergraduate, physical science, gaze fixations differences

1. Development of Research Questions

One of the overlying aims of education research is to help students learn more effectively and/or efficiently. Since the college “lecture” hall is one of if not the first place a student learns about the content, it is important to maximize the time for the students in that class. Having one instructor for a large number of students can
complicate this because it allows students to disappear into the crowd and thus can lose attention or interest in the class. Thus, there is a great deal of emphasis on the person teaching the course.

As a physics education faculty member, I teach physical science content courses (the subject of this study) to future elementary school teachers and pedagogy courses to secondary science (physics and chemistry) teachers. Part of the role with those pre-service secondary teachers is to observe them in the field and to have them video tape themselves teaching where we as a group can analyze their classroom teaching. This started me to reflect upon my own teaching. Yes, I modify lectures, materials, and how I present information, but why is it that we as faculty do not videotape ourselves teaching and observe those videos? Many possible answers came to mind, but none that justified me not doing this in my own classroom. I have done research with eye-trackers in problem solving in physics and the abilities of this equipment led to the inclusion of eye-trackers in this study because a portable eye-tracker will not only show me my lecture, but shows me how my students view my lecture.

This paper works on the premise that if a student is not paying attention in this environment, then it can be said they are also not learning. Thus, we can generally assume that it is better to have our students on-task and paying attention in class as opposed to being off-task and not paying attention. This makes one of our goals as educators to find ways to maximize the amount of time students are on task and are paying attention. It is true that an eye-tracker does not tell us what the subject is thinking. For example, a student may be looking at the wall and it is impossible to tell if they are thinking about what was just said in class or if they are thinking about what to
make for dinner. Combining this with what they are looking at before and after, discussions being made can give some insights.

Most educators may call the environment of this study (one instructor with 48 – 72 students) a lecture. This would be correct in many instances. However, I will use the term “large-group instruction” or LGI. The reason I do not call it a typical lecture is because the instructor does not stand in front of the students the entire time talking to them and the students passively listen and learn. Rather, the instructor helped facilitate discussion, debate and construction of knowledge for the students in the classroom. Specifically, the instructor followed the I.S.L.E. methodology (Etkina & Van Heuvelen, 2007). Even in this LGI environment, student attention is paramount.

Thus, the goal of this study was to analyze student attention in the classroom by utilizing an eye-tracker. The students wore the eye-tracker during class and I recorded what student’s focused on during the course of the lesson. This data allowed me to investigate the following questions:

Research Question #1: What percent of the time is a student on task during LGI?
Research Question #2: What will divert the attention of a student?
Research Question #3: What do students focus on during an LGI?
Research Question #4: What is a student’s attention span during a typical class?
Research Question #5: What keeps a student on task during an LGI?
Research Question #6: What regains a student’s attention after it has been lost?

The answers to these questions will provide insight concerning the importance of how we teach our introductory science courses at the university level. The big picture of these research questions is if we better understand what keeps our students focus during a
lecture, then we are able to change how we teach our lectures to maximize the amount of
time our students stay on task. As an instructor who uses guided inquiry throughout the
course, this study serves as a tool to help show the effectiveness of this instruction.

2. Conceptual Framework

2.1 Eye-Tracking: Why Incorporate it into Research

Eye-tracking is a valuable method of visualization and analysis of a viewer’s
distribution of visual attention and cognitive state. The scanpath serves as an indicator of
attention and the sustained focus of cognitive resources on information while filtering or
ignoring extraneous information (Anderson, 2004). Tracking eye movements thus shows
shifts in attention. One way to explain shifts in attention is the moving-spotlight theory in
which attention can be thought of as a spotlight that moves as focus is directed towards
intended targets. When the spotlight illuminates information, or when information is
attended, more efficient information processing can take place. However, during spatial
shifts of attention this spotlight is turned off while attention shifts towards the next
attended location (LaBerge & et al., 1997; Posner & et al., 1984). This shift in attention
takes place in three mental phases: (a) a subject disengages attention from the current
focus, (b) a shift in attention to the new location occurs, and (c) attention is finally
engaged at the new location (Sperling & Weichselgartner, 1995).

Eye-tracker methodologies are the only tool available that give us the opportunity
to determine where, when, and on what subjects visually focus during a class. Other
studies (described later) only use extrinsic methods (observation, analysis of notes,
interviews, etc). The eye-tracker is the only option available to allow researchers to
investigate how students view our classes. The eye-tracker also helps us investigate in
what order students look at information presented to them, how long and what they prefer
to look at. A deeper analysis in the future will involve breaking down these studies by gender, age, location in the classroom and grade point average.

2.2 Student Attention

Two of the biggest beliefs regarding student attention are that it typically only lasts the first 15 minutes (Davis, 1993; Goss Lucas & Bernstein, 2003; Wankat, 2002) or 20 minutes of class (Macmanaway, 1970) and that the longer a student is in a class, the more their attention span decreases (Johnstone & Percival, 1976). Wilson and Korn (2007) provided a thorough review of the multiple research methods that helped to come up with these ideas who also challenged those two beliefs. Multiple methods previously used to study student attention were: note taking, observation, retention, and self-report and in these studies, many of them report attention as a function of time over the class.

Note taking involves analyzing the amount of notes and the time students take them during a class. Studies (Hartley & Davis, 1978; McKeachie 1986, 1999) have shown that the amount of notes taken during a class decrease while others (Hartley & Cameron, 1967; Maddox & Hoole, 1975) show that it remains constant. The debate then begins with the relation between note taking and attention. A lot of the reduction in student note taking was due to the content, not necessarily fatigue (Hartley & Cameron, 1967).

Observations involve a researcher watching the actions (or the amount of restlessness) of a single student or in an entire class. One of the most referenced studies is from Lloyd (1968). Lloyd plotted his observations from his classes (along with discussions from colleagues) and made a timeline of student attention in a 50 minute class. The first 5 minutes shows the highest degree of attentiveness and then at the ten
minute mark, the attention begins to decline. The attention picks up in the last 5 minutes of the class, presumably because the students know the class is almost over. Johnstone and Percival (1976) also analyzed student attention via observations. Overall, their work showed a lower amount of attention in the beginning of the class, followed by the next lull in attention between 10-18 minutes into the class. They also noted a great deal of variability among classes and instructors. These studies are important because I have done the same type of timeline except using eye-tracking data.

In retention, students are given a recall test immediately after the class. McLeish (1968) discussed previous work that showed students who listened to only 15 minutes of a class scored higher on a recall test compared to students who listened to 40 minutes of class (41% versus 20%). When McLeish replicated this with a live instruction, he found no difference in retention.

Self-report is a situation where the subjects respond in regular time intervals with their amount of concentration. Stuart and Rutherford’s (1978) study involved 1,353 students who, every 5 minutes, gave their level of concentration. What they discovered was that the highest level of concentration occurred between 10 and 15 minutes from the start of the class and that this trend was consistent among all classes. However, there was a considerable amount of variability among instructors.

Student attention is very difficult to study, however we do have some insights. Wilson and Korn (2007) state in their conclusion that:

It is clear that students’ attention does vary during lectures, but the literature does not support the perpetuation of the 10- to 15-min attention estimate. Perhaps the only valid use of this parameter is as a rhetorical device to encourage teachers to develop ways to maintain student interest in the classroom. If psychologists and other educators continue to promote such a parameter as an empirically based estimate, they need to support it with more controlled research. Beyond that,
teachers must do as much as possible to increase students’ motivation to “pay attention” as well as try to understand what students are really thinking about during class.

This study provides a new method to study student attention. By combining this methodology with those listed above we can better understand our students’ behaviors in the classroom. By analyzing scan paths, we can find what students “pay attention” to and help other instructors learn what they need to do to improve their classes so that more students will pay attention in them. This is another way to measure how students’ attention varies in class and as Wilson and Korn put it, teachers must do as much as possible to increase students’ motivation to “pay attention.”

3. Method

3.1 Context

The class I conducted this study in is an integrated physical science course for pre-service elementary education majors called ISCI 2002. Two-thirds of the class focused on physics topics while the rest was a split between chemistry and astronomy. The class had two sessions a week of one hour and fifteen minutes (data was collected here) as well as a two hour lab component. Both classes had the same instructor who taught this course many times before the start of this study. ISCI is a required course for all elementary education majors in the state of Georgia. The course was predominantly female students who were the traditional college student (aged 19-23). This course was at a suburban university whose student population is about 24,000 students.

The instructor did not modify his teaching in any way for the study. He did follow the Investigative Science Learning Environment (ISLE) format (Etkina & Van Heuvelen, 2007) – a guided inquiry learning system that engages students in the active construction of knowledge mirroring the processes used by physicists to acquire knowledge during the
physics parts of the course. The chemistry and astronomy portion were more lecture based with aspects of ISLE interwoven throughout.

The ISLE curriculum emphasizes observations, then developing a model based on those observations and finally testing that model. Thus the course was designed to have students construct knowledge for themselves and then discuss their ideas with their partners. These ideas could be testing their model, a variety of assessment tasks, or discussing their observations. In this large group setting there was a large amount of dialogue between and among the students.

The professor is well versed in Physics Education Research and through the ISLE curriculum utilized assessment tasks such as talk to your neighbor tasks, a variety of assessments, simulations and multiple representations (Rosengrant, 2011; Rosengrant, Etkina & Van Heuvelen, 2006, Rosengrant, Van Heuvelen & Etkina, 2009). The professor consistently receives high evaluations in terms of helpfulness and clarity while the students also comment on the high degree of difficulty and was awarded Distinguished Teacher in the College of Arts and Sciences this year. There are practically no demonstrations in the class because the pre-service teachers will have little if any funds for their classroom so the professor wants to allow anything he does in the classroom to be available to his students in their future classrooms. However, he does rely on power points which are made available to the students before the class (minus the answers). Some students chose to print them out while others did not (which is a variable to be investigated in the future) while some too notes directly on laptops where the notes were downloaded. The answer slides to the powerpoints are made available after the class is over.
3.2 Sample

A preliminary study was conducted in the Spring of 2011 (Rosengrant et al., 2011) and then that data was reanalyzed to help format future work. This study was conducted in two consecutive semesters (Fall 2011 and Spring 2012). The fall semester had 44 students while the spring semester had 70 students.

The data for the study came strictly from students wearing the eye-tracker. One student would wear the eye-tracker each class with the exception of the first and last class and during days there were an exam. In the fall semester, 6 students were selected from a list of volunteers in the class. The original intent was to have 6 students who wore the classes 4 times each to look for patterns in the same student but. Each student was reimbursed $10 per class for wearing the glasses. The students were initially selected on two factors: if they could wear the eye-tracker and if they provided good data (i.e. Tobii has a ranking system in the software on a scale of 1-5 stars for calibration so any student who had less than 3, a different student was selected for the study). After those initial conditions were met, the students were selected based on age, GPA entering the course and gender so that these differences could be studied in the future. Out of those 6 students, 3 wore the eye-tracker for 5 different classes, 1 wore it for 3 classes, 1 wore it for 2 and then the last student only wore it 1 time. The student who wore it for 3 classes was typically late (or did not come to class) so the equipment could not be calibrated at the start of class. The student who wore it 2 times developed an allergic reaction to her contacts, thus could not wear the eye-tracker because it cannot be used well with students with glasses. The student who only wore it one time was the only one to have dropped the class in the first few weeks. Three classes were also missed due to problems with the
eye-tracker.

The fall semester helped modify the study for the spring semester. The spring study contained 8 students who each wore the eye-tracker 3 times. This semester used 8 students to eliminate the chance if students dropped out and to allow for suggestions for correlations with attention to such factors as age, gender, gpa. Again, almost all lectures were covered with the study except the first, last and the exam days. The spring semester had the exact same content, same professor and was taught following the exact same instructional model.

3.3 Instruments and Data Collection Procedures

I used Tobii’s latest eye-tracker called Tobii glasses. The glasses are a portable eye-tracker that records data for 70 minutes. The data combines audio and video with a dot representing where they look (see Fig. 1 - Left). The glasses record data at a rate of 30 Hz. Figure 1 - Right shows a student wearing the glasses in class. Each subject wore the glasses for the whole lecture. All of the factory settings were used for the eye-tracker.

![Figure 1](image.png)

**FIGURE 1:** Picture on the left is a sample of the data output. Picture on the right is a student wearing the glasses.

After every class the data was downloaded and backed up. The data is in the form of a video which was analyzed without analysis software packages. Once the semester
was over, the videos were broken down into one second intervals and coded based on certain criteria. The data was not analyzed until after the semester was over so that the data would not affect classroom instruction in any way. A subject was labeled as “on task” if they were looking at the instructor, the board, the notes, their neighbor (during assessment questions) or something else related to the class. The subject was labeled as “off task” if they were looking around the room, at other classmates, looking at computers or cell phones or something else not related to the class. The times during the class, typically after a quiz, where the instructor was collecting papers but not teaching was coded as “down time.” Finally, if no data could be obtained, this was a separate code.

The data was coded into an excel file. The maximum amount of time the eye-tracker could collect data is 70 minutes, thus a maximum of 4200 data points per class. Each code was tallied per class and then for the entire semester which was converted into a percentage. Each code was then combined into the larger categories of Off Task, On Task or No Data (which includes down time). On Task was coded as 1, Off Task was coded as 0 and No Data was left blank. Each minute of class time was then averaged to give a percent of time that the students were on task in that class. For example, if 48 seconds out of 60 seconds, the student was “On Task” then that minute would be 48/60 or 80% of the time On-Task. However, if there was a minute were part of the time was No Data then we took the average of the data we had collected. If 5 seconds of those there was no data, 48 seconds of it was coded as On-Task, then we would actually have 87% of that minute as On-Task (48/55).

If there was video data but no audio data for some reason (this happened rarely)
this was coded as no data as the verbal descriptions help impact the difference between off and on-task. At extreme angles the eye-tracker tended to lose where the eye was looking. An example of this is if a student was taking notes, they would typically look downward with their eyes and not move their entire head downward. Though there was no eye-tracking data, this was still coded as on task because the video showed them taking notes just like if they were texting on their cell phone we labeled that as off task.

3.4 Findings

To investigate the first three research questions: (1) What percent of the time is a student on task during LGI? (2) What will divert the attention of a student? and (3) What do students focus on during an LGI? I counted up the number of seconds each subject looked at each of the particular codes and present the results in Table 1.

<table>
<thead>
<tr>
<th>Code</th>
<th>Full Year</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Data</td>
<td>0.98</td>
<td>0.84</td>
<td>1.10</td>
</tr>
<tr>
<td>On Task: Professor</td>
<td>24.59</td>
<td>21.79</td>
<td>26.97</td>
</tr>
<tr>
<td>On Task: Board</td>
<td>29.55</td>
<td>30.88</td>
<td>28.42</td>
</tr>
<tr>
<td>On Task: Notes</td>
<td>24.01</td>
<td>28.16</td>
<td>20.51</td>
</tr>
<tr>
<td>On Task: Classmate</td>
<td>5.18</td>
<td>5.57</td>
<td>4.85</td>
</tr>
<tr>
<td>On Task: Assessment</td>
<td>1.60</td>
<td>2.04</td>
<td>1.23</td>
</tr>
<tr>
<td>On Task: Other</td>
<td>1.44</td>
<td>0.52</td>
<td>2.22</td>
</tr>
<tr>
<td>Down Time</td>
<td>2.50</td>
<td>1.82</td>
<td>3.08</td>
</tr>
<tr>
<td>Off Task: Classmate</td>
<td>2.19</td>
<td>1.53</td>
<td>2.75</td>
</tr>
<tr>
<td>Off Task: Computer</td>
<td>2.79</td>
<td>4.18</td>
<td>1.62</td>
</tr>
<tr>
<td>Off Task: Room</td>
<td>2.03</td>
<td>1.22</td>
<td>2.72</td>
</tr>
<tr>
<td>Off Task: notes</td>
<td>0.32</td>
<td>0.58</td>
<td>0.10</td>
</tr>
<tr>
<td>Off Task: Other</td>
<td>2.80</td>
<td>0.88</td>
<td>4.43</td>
</tr>
<tr>
<td>Total On Task</td>
<td>86.38</td>
<td>88.96</td>
<td>84.19</td>
</tr>
<tr>
<td>Total Off Task</td>
<td>10.13</td>
<td>8.39</td>
<td>11.62</td>
</tr>
</tbody>
</table>

To determine an answer to question #4: What is a student’s attention span during a typical class? I took every code and re-coded them as a 0, a 1 or a no code. A 0 was anything labeled as off task, a 1 was for anything labeled as on task and if there was no
data or down time, this was not coded or left blank. Thus every second was a 0, a 1, or a blank. I then averaged these numbers for every minute. I took the number of minutes they were on task and divided it by the total number of minutes of data. For example, if a subject was on task for 49 out of the 60 seconds then that would be coded as $49/60 = 0.82$ or 82%. If however there was 5 seconds of no data, then it would be averaged out to be $49/(60-5) = 0.89$ or 89%. Every minute of every class was coded as a percent on-task. This average was combined with every other class in the semester to get a minute by minute average of on task time during the lecture. This results in Figures 2 and 3 showing the percent of time the students paid attention during the course of a class both in the fall and then in the spring.

**FIGURE 2:** Chart showing the percent of time students spent on task in the Fall 2011 class (% on task per minute of class).
FIGURE 3: Chart showing the percent of time students spent on task in the Spring 2012 class (% on task per minute of class).

The two charts are similar. The only difference between the Fall and Spring is that the Fall had fewer students and was in a smaller rectangular (compared to a semi-circular) classroom. The attention span was consistent over the entire class which contradicts some attention studies described earlier. However, there are differences with the reanalysis of the preliminary data study (Fig. 4) (Rosengrant & Hertainment, draft).

FIGURE 4: Chart showing the percent of time students spend on task in the Spring 2011 class of the preliminary study (% on task per minute of class).
One of the differences between Figures 2 - 4 occurs in the first five minutes. In the year-long study, there is lower percentage of on-task time during the initial minutes. In the preliminary study there is a decrease in the percent of on-task time in the last part of the class. Possible reasons why the year-long study shows the first five minutes distinctively lower is that there were a few students who spent the beginning of class getting notes ready, catching up with their neighbor or not listening to the introduction.

The preliminary study data could also be skewed in the fact that the material was mostly chemistry and astronomy and not physics. Since the instructor was well versed in physics education and those classes follow a guided inquiry model while the later were more lecture orientated definitely change the attention span of students. More analysis will be needed in the future.

Another way to analyze this data (though only one sample will be done here) is to analyze an individual student. This helps answer research questions 5 and 6 (What keeps a student on task during a LGI? and What regains a student’s attention after it has been lost?) and expands upon the other research questions (Fig. 5).

**FIGURE 5:** Chart showing the percent of time an individual student spent on task in one specific class.
There are two gaps in the timeline in Figure 5; these are due to times where the entire minute is coded as blank, either downtime or no data. In the first minute the gap is because class has not started yet and we were working on testing the equipment and the second gap is because the subject had taken a quiz previously and was done with the quiz.

Though most of the dips in On-Task time only drop to about 80% (which is about 10-12 seconds out of 60 being off-task) the drops do convey information as to why students do not pay attention. For example, the drops at minutes 19, 25, and 63 show the student as off-task, but these are all situations where the class had a “talk to you neighbor activity” and the student was done answering the question with her neighbor and started talking about non-class related things. However, the drops at minutes 2 and 6 relate to the fact that we were reviewing for the quiz and the student was watching other students in the classroom during the review. Perhaps this was due to the fact that the student knew the information or is just genuinely disinterested in hearing the material again, or because it was only a few seconds during the minute, that reviewing may cause students to tune out faster because they have already heard it. Likewise the drop at minute 13 was when the instructor was reviewing the quiz they had just taken. The decrease starting at minute 37 had nothing particular with the content, but rather the student just started talking with her neighbor and playing with her pencil.

However, it is important to note that this is the spot where one content area was wrapping up and a new one was beginning at minute 39. These could be the reasons why starting at minutes 27 and minutes 43 show an extended attention span. At minute 27 a new topic is being introduced while minute 43 marks the start of a new chapter.
4. Discussion

4.1 Implications for Instruction

As stated previously the big idea behind this study is to continue to find ways to improve how we deliver our content to students. The data presented here suggests that guided inquiry can be an effective form of instruction in large lecture halls. The key point is that it is possible to maintain your students’ attention throughout an entire 75 minute class. How someone can do this in their own classroom include several different factors.

The things that made this class successful were the fact that the instructor created a supporting culture in the classroom without sacrificing content. Humor through the use of stories or videos to highlight physics principles helped maintain student attention and also contributed to that culture of support. If students are not comfortable going to a class, then it will be more stressful for them and will cause them to be less likely to learn. A constant use of assessment tasks beyond multiple choice questions where students have a chance to interact and discuss may lead to some off task time after the discussion is over but they are critical to help students succeed in the class. These assessments also help to break up the class so students can refocus their efforts.

4.2 What is the broader value of the research?

This type of work extends beyond just the physical science classroom. In the education profession as a whole, it is not just physics that has these large lecture hall type settings. This work can be extended into other science disciplines such as biology, chemistry as well as disciplines outside of science such as mathematics. It goes beyond the college classroom and can extend into the K-12 setting.

4.3 How does this work contribute to your domain?
Regardless of age, grade or discipline as a teacher we want our students to learn the material we present. Education fails if those we try to help do not receive it because we could not convey the material to them. This study is the first of its kind where we can follow what students are looking at during the course of a typical classroom. This ultimately helps us learn how to improve our instruction as educators. If we improve our instruction, then we can increase the chances that our students will receive the education we desire to give them. A teacher needs to reflect on his or her practice no matter how difficult that reflection can be to the teacher.

5. Limitations

Finally, it is important to discuss the limitations of the study. Eye trackers are a tool that provides additional data that was not previously used to study student attention. However, the eye-tracker only shows us where they are looking, not what they are thinking. A student could be looking at the instructor, but thinking about the plans they have for the weekend ahead. This action would be labeled as on task though the students are not paying attention.

A limitation of the equipment is it only records data for 70 minutes while the lectures were 75 minutes. At extreme angles the image of the eye is lost (though it was still coded unless it could not be determined what the subject was doing, then it was coded as no data). Finally, though not significant, there was a delay between the video and the audio that got progressively larger as the recording continued.

Finally, we need to be very conscientious of the Hawthorne effect (Festinger and Katz, 1953). This is an effect where subjects change their normal behavior simply because they are part of an experiment. It is tough to say how prevalent this effect was
because in many sessions, the subjects were occasionally doing things that were discouraged in lecture, mainly texting on the cell phone yet during other portions of the research the subjects commented that they needed to be on their best behavior because they were being studied.

6. References


Rosengrant, D. & Hearrington, D. (draft). A reanalysis of eye trackers and student attention. Will be submitted online at eyetrackerjournal.com


