Introductory Astronomy as a Measure of Grade Inflation

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ABSTRACT

We use four years of introductory astronomy scores to analyze the ability of the current population to perform college level work and measure the amount of grade inflation across various majors. Using an objective grading scale, one that is independent of grading curves, we find that 29% of intro astronomy students fail to meet minimal standards for college level work. Of the remaining students, 41% achieve satisfactory work, 30% achieve mastery of the topics.

Intro astronomy scores correlate with SAT and college GPA. Sequential mapping of the objective grade scheme onto GPA finds that college grades are inflated by 0.2 for natural sciences majors, 0.3 for social sciences, professional schools and undeclared majors), 0.5 for humanities majors. It is unclear from the data whether grade inflation is due to easier grading curves or depression of course material. Experiments with student motivation tools indicates that poor student performance is due to deficiency in student abilities rather than social factors (such as study time or decreased interest in academics), i.e., more stringent admission standards would resolve grade inflation.

1. Introduction and Overview

One of the most popular science courses taken by non-science majors at today’s universities are introductory astronomy classes. It is hoped that non-science students are attracted to the wonder of the cosmos and a wish to understand the mysteries of the Universe. However, exit student evaluations frequently complain of the amount of math and physics in astronomy courses, suggesting that their initial enthusiasm for the topics is mediated by the unexpected difficulty of the material.

Despite complaints on exit evaluations, these survey courses continue to be extremely popular and a significant fraction of non-science majors pass through intro astronomy to fulfill University science requirements. Like all major universities, the University of Oregon also offers a series of introductory astronomy courses aimed at non-science majors needing to fulfil general education requirements. These courses appear to be more highly attended than other science classes of the same level, although it is not clear how total enrollment numbers would directly compare to other science departments since there has never been a term where all the offered sections were not filled.

The attractive nature of the introductory astronomy courses makes them ideal laboratories for tracking student cognitive abilities and objective grading techniques since they address a wide range
of students in terms of ability, class rank and selected major. They also have a high percentage of students with undeclared majors, the portion of the student body most at risk of dropping out of college before completing a degree program. In addition, the University of Oregon also has the social science advantage of admitting a broad range of student aptitude (some faculty would argue the admission standards are too broad) and a homogeneous student population that eliminates a majority of ethnic and geographical influences (we are composed primarily of Caucasian students from the Pacific Northwest).

In this paper, we present a study of student astronomy scores for four identical classes taught between 2005 and 2009. The conditions for the course (exams, quizzes, class size and student distribution) were unchanging from year to year. This allows a large sample size to compare achievement in the course with various cognitive factors such as SAT score and GPA. We also apply a unique set of exams to test a students mastery of the subject material in an objective fashion, independent of the typical grade curves used to estimate student performance. This allows us to compare objectively assigned grades (albeit from a narrowly defined topic, astronomy) to the wider defined GPA as a measure of grade inflation. This technique will also be used to estimate the percentage of students who are capable of college level work (versus the estimates obtained at admission standards). The goal of this project is to present a framework for objective standards and define preliminary techniques to estimate the cognitive abilities of the current student population.

2. Advantages to ASTR122

The course selected for our study is ASTR122 (Birth and Death of Stars course, see http://abyss.uoregon.edu/~js/ast122), one of three introductory astronomy classes taught at UOregon. There are several conditions to the ASTR122 course that makes it unique for this type of study. For example, economic conditions have eliminated teaching assistant support for introductory astronomy at UOregon. The lack of discussion sections encouraged us to move to an on-line quiz system to supplement the lecture/exam component. Thus, the variable of a range in TA quality is removed and more mathematically intense problem sets were added to the course material. On-line material and quizzes means that scores could be automatically tracked and analysis greatly eased.

ASTR122 presents a more restricted range of physics and math topics than other sections of introductory astronomy, focused primarily on the stellar astronomy. Our other ASTR courses deal with the solar system (thus, atmospheric chemistry, orbits, gravity, biology, geological processes, etc.) or cosmology (spacetime, relativity, expanding universe, early universe processes, particle physics, etc.) and suffer from a broad range of topics and underlying science. ASTR122 has the advantage of a more focused set of physics topics and repeatable mathematical problem sets, leading to the expectation of more uniformity in student scores.

In addition to the uniformity in course structure and topics, there was an extra advantage in that (unbeknownst to the students) the exact same exam and quiz questions were used for all
classes over 4 years. This removes any chance that, by random question selection, some terms used particular difficult questions compared to other terms. This, of course, brings up the possible cheating; however, there is no indication of that in the distribution of scores. Some amount of in-class cheating was detected on the exams (based on correlated wrong answers on the exams) and these students withdrew from the course and, thus, the dataset.

3. Course Structure

The ASTR122 courses (all taught by the author) were designed to 1) emphasize mathematical reasoning (with the forum of understanding stellar astronomy) and 2) present an objective grading system in order to evaluate the actual level of college material the current student population can handle. Mathematical problems were the domain of the on-line quiz system. Examples are worked out each lecture (on the blackboard) and the quizzes have deadlines several days after each lecture allowing for sufficient time for the students to work out the solutions (and seek assistance). These were scored automatically, and the results (plus solutions) posted immediately after the deadline (providing rapid evaluation for the students).

Knowledge testing was the domain of the multiple choice exams. Three exams are taken each term (covering only the previous 1/3 of the course material). Each exam is composed of 100 multiple choice questions. Each exam is divided into three types of questions. The first type tests knowledge of factual information (e.g., what is the color of Mars?). The second type of questions addresses the students ability to understand the underlying principles presented in the course (e.g., why is Mars red?). The third type of questions examines the ability of the student to process and connect various ideas in the course (e.g. why is the soil of Mars rich in heavy elements such as iron?).

Excellence in answering questions of the first type represents satisfactory grasp of the courses objectives, i.e. a ‘C’ grade. High performance on questions of the second type demonstrate good mastery of the course material, i.e. a ‘B’ grade. Quality performance on the top tier of questions would signify superior work, i.e. an ‘A’ grade. While the design of the various questions may not, on an individual basis, exactly follow an objective standard for ‘A’, ‘B’ or ‘C’ work, taken as a whole this method represents a fairly good model for distinguishing a students score within what most universities consider a standard grading scheme. Certainly, this was the original intent of the ABCDF grading scheme, not to assign a grade based on class rank or percentage, but to reflect the students actual understanding of the core material.

With this technique applied to every exam, it is possible to assign an objective pass/fail line at 45%. Note, that correctly answering all the bottom tier questions on a single exam, 33 of them, results in a score of 33%. But, the student would then guess the remaining 66 questions for a total score of $33 + 66/5 = 46\%$. Likewise, the separating point between ‘C’ and ‘B’ is 60% and between ‘B’ and ‘A’ is 73%. The final grade for the course is assigned by summing the exam quiz scores and weighting the exams by 2/3’s and the quizzes by 1/3, then normalized to a 100 point system.
4. Characteristics of the Student Population

The course was taught every year from 2006 to 2009 by one instructor (the author). Enrollment stats are shown in Table 1. The large number of withdraws is due to the fact that UOregon allows students to withdraw from a course up to the 7th week of our 10 week terms (!). Almost all of the withdraws would have received failing marks, regardless of their remaining exam and quiz scores. In fact, it is surprising that any students fail this course as by the 7th week they have completed two exams and 2/3's of the quizzes. This should provide the student with a remarkably accurate estimate of their final grade (95% of students failing by the 7th week fail the course). Interviews with failing students indicates their decision to remain in the course is a mixture of 1) a poor understanding of the arithmetic behind the grading scheme, 2) a overly optimistic opinion of their ability to overcome a failing score with the last exam and quizzes and 3) complete disregard of their scores and the impact on their grade for the course.

Unsurprisingly, the classes were primarily composed of lower classmen (freshmen and sophomores, 69%) with equal numbers of juniors and seniors (see Table 1) as is typical for survey courses. The majors for the population, divided crudely into five categories, are 1) 54 (7%) natural sciences, 2) 128 (16%) social sciences, 3) 255 (33%) professional schools, 4) 135 (17%) humanities and 5) 211 (27%) undeclared. This distribution is driven, primarily, by the university general education requirements for non-science majors. The high number of undeclared majors reflects the predominant lower classmen component to the classes.

SAT_M and SAT_R scores for the student population are shown in Figure 1 as normalized histograms (592 students). ACT scores were converted to SAT equivalents using standard ACT to SAT concordance tables. The peaks and means were identical from course to course. The SAT_M peak is slightly higher than SAT_R, which is unusual in that, for the general student population, this trend is reversed. It seems to indicate that students who elect to take introductory astronomy are slightly more math proficient that the typical university student.

5. Analysis

The normalized histograms of the ASTR122 total scores for each class are shown in Figure 2. The means were 56.5, 54.1, 56.7 and 56.3 with standard deviations of 12. The peak scores were also nearly identical. The identical mean scores are not too surprising given the uniformity of the course structure and the identical nature to the quizzes and exams. However, total University enrollment numbers increased by over 30% during the same time period, so there was some expectation that mean scores would decrease (as the timescale for human evolution of intelligence was longer than the increase in enrollment numbers). We note that given the definition of our grading standards,
Table 1. Enrollment ASTR122 by term

|       | Fall 07 | Fall 08 | Spring 08 | Fall 09 | Total |
|-------|---------|---------|-----------|---------|-------|
| Freshmen | 79      | 76      | 57        | 89      | 301 (38%) |
| Sophomore | 56      | 51      | 73        | 63      | 243 (31%) |
| Juniors  | 23      | 34      | 34        | 33      | 124 (16%) |
| Seniors  | 22      | 24      | 45\(^a\)  | 24      | 115 (15%) |
| Total    | 180\(^b\) | 185\(^b\) | 209       | 209     | 783   |

\(^a\) A surge of seniors in the spring term reflects a number of graduating students desperate to complete science requirements before spring graduation.

\(^b\) A decrease in total enrollment was due to a smaller classroom.

Table 2. Score Distribution by term

|       | Fall 07 | Fall 08 | Spring 08 | Fall 09 | Total |
|-------|---------|---------|-----------|---------|-------|
| Withdraws | F (failure) | 19      | 20        | 35      | 30    | 113 (14%) |
| <45    | F (failure) | 23      | 39        | 30      | 24    | 116 (15%) |
| 45 to 60 | C (satisfactory) | 79      | 75        | 83      | 89    | 326 (41%) |
| 60 to 73 | B (good)   | 41      | 38        | 43      | 56    | 178 (22%) |
| > 73   | A (superior) | 16      | 13        | 19      | 13    | 61 (8%)  |
Fig. 1.— SAT Math and Reading for the ASTR122 students. The math scores are slightly higher than the general student population (perhaps a natural selection away from physical sciences by students with weak math scores).
these mean ASTR122 scores correspond to approximately a C+ (versus the common B- used in grading curves).

Given the attempt to design the course to objectively assign ‘satisfactory’, ‘good’ and ‘superior’ level work, we can convert these total scores into those categories. To this end, we assign failure, as outlined in the last section, to scores less than 45%. Satisfactory work (i.e. ‘C’ level) falls in the range of 45% to 60% (i.e. 1/2 the distance between the failure line and the 2/3'rds line for ‘B’ level questions, adjusted for guessing, 66.6 - 33.3/5). Good work falls between 60% and 73% (i.e. ‘B’ level). And superior work lies above 73% (i.e. ‘A’ level, 66.6 + 33.3/5).

Table 2 displays the score breakdown for all 794 students. Withdraws were treated as failures. While there are cases where a student with a high score was forced to withdraw for non-academic reasons, this was rare. A vast majority of the withdraws had failing scores up to the point of withdraw. Combined withdraws and failures means that 29% of the students did not reach the minimal requirements for satisfactory understanding of the material. About 41% of the students achieved a level of ‘satisfactory’ performance based on exams and problem sets. Only 22% achieved ‘good’ or ‘B’ level work and an additional 8% reached a level of ‘superior’ or ‘A’ level work.

If these percentages reflect overall college performance, we are faced with a scenario where almost 1/3 of admitted freshmen are ill prepared for college level work (even at an introductory level) or, if they have college skills, fail to apply them. Those numbers match freshmen retention and graduation rates for many universities (the University of Oregon being at the low end of AAU institutions where retention rates are 80%); however, these numbers directly impact on admission and retention strategies as our data indicates that financial or social reasons are not the primary reason for student’s withdrawing from college.

In addition, only 1/3 of the student population seem capable of ‘mastery’ level work (above the ‘B’ level), even for an introductory course. The remaining population does adequate work, which will probably continue into their upper division courses (see §6). Whether the reasons for this are due to intelligence, work ethic or simple motivation to perform can not be fully addressed by this study, but, again, all indicators are that many undergraduates do not obtain a full education under the current higher education system.

Mean total scores do not vary between students majoring in humanities, social science, professional school or undeclared (means of 55±12). However, natural science students have a mean score of 61±13, significantly higher than other majors. This is probably due to an higher familiarity with math and science terminology; however, similar scores across other majors will be important in the comparison between scores and GPA as a measure of grade inflation (see §7)
Fig. 2.— The normalized histograms for total course score in ASTR122 for the four terms listed in Table 1. Peaks, means and variance are identical to within the errors.
Fig. 3.— Combined SAT score versus ASTR122 score. The correlation between SAT score and ASTR122 score is obvious.
6. SAT Scores, GPA and ASTR122

We can investigate the effect of IQ or ‘g’ component values on class scores by comparing SAT scores to ASTR122 total scores. A plot of composite SAT score (math plus reading) versus total course score is shown in Figure 3. The correlation is evident ($R=0.49$) and also visible in $SAT_M$ versus course score (less obvious in $SAT_R$ versus course score which is unsurprising due to the mathematical nature of the course). Due to the large number of data points, a better method to display the dataset is with a density distribution, where the data points are binned on a 2D grid and number of points determines the intensity of each grid pixel. The density distribution for SAT scores is shown in Figure 4, along with a moving average (red symbols) and the peak values in SAT bins of 100 (green line). While there is a range of scores in each SAT bin, the trend for increasing ASTR122 score with increasing SAT score is obvious. The upper left portion of this diagram is nearly empty, indicating that even extremely conscientious, hard-working students can not overcome the factors that produced their low SAT scores.

This is dramatically different from our comparison of SAT scores and upper division GPA (by major) in our study of over 4,000 students across 17 majors (Hsu & Schombert 2010). In that study, there were a significant fraction of students who obtain high GPA’s (greater than 3.5) out of proportion to their SAT scores. Presumably, they achieve this academic success through diligence and hard work; however, these same factors should apply to introductory astronomy students. And yet, the ASTR122 scores are much more strongly correlated to an IQ measurement than any other college performance indicator.

There are several possible reasons for the difference in SAT to GPA/score correlations. For example, the very nature of science and mathematical knowledge may form a gap between a students cognitive ability and the threshold needed to master a science topic. No amount of hard work can overcome deficiencies in science background that have their origin from primary and secondary education. Another possibility is that students in introductory courses are simply not motivated to work as hard as they do for courses in their major. Upper division courses also naturally have a population of students who have completed their first couple years of study. Introductory survey courses have a large fraction of the students who will dropout by their junior year. And this population comprises a majority of the lower tail of the grade distribution where the problem lies.

One could argue that the results from this study only apply to a particular scenario, non-science majors performance in an astronomy course. However, the performance, as measured by course score, is also highly correlated with overall college GPA. Figure 5 displays this data, again as a density distribution due to the large number of data points. The Pearson correlation coefficient is 0.65, which is as high than any know ‘g’ component correlation to college scores. It seems, by some unknown factors, that ASTR122 is a high predictor of total college performance, stronger than SAT or ACT scores (Hsu & Schombert 2010).

Figure 5, and the correlation with SAT score, raises an extremely disturbing possibility; that survey courses of this type are not evaluating a students ability to learn the material (in this case,
Fig. 4.— Combined SAT score versus ASTR122 score, density distribution. Shaded pixels are the data density, red points are the moving average and the green line is the peak (in bins of 75). All three demonstrate the strong correlation between SAT score and ASTR122 course score.
Fig. 5.— Overall GPA versus ASTR122 course score. The correlation between ASTR122 and overall GPA is stronger than any predictor of college performance.
stellar astronomy) but rather serving as massive IQ tests (fine tuned for college skills). While one expects smarter students to perform at a higher level, there is no evidence in these scores that students perform above their expected levels (i.e. they become educated by the course material) as is seen in upper division GPA by the time they graduate.

7. Grade Inflation versus Course Content Depression

Clearly the distribution of objective grades outlined in the previous section would be unacceptable to the student population (probably university administrators and parents as well). It is these same social forces that drive grade inflation (outlined in numerous studies, see http://gradeinflation.com). We will not elaborate on these forces here. Instead, we can map our expected grades onto overall GPA as a measure of the effects of grade inflation to the general student population. Note that this mapping assumes that the objective grading method, outlined in §2, does accurately measure a standard that would be agreed upon by most university educators as consistent with the current interpretation of 'A' through 'F'. This is the premise for this entire study and is only supported by the tight correlations between ASTR122 total scores and SAT score/GPA.

Using Figure 5, and a least square fit to the moving average, we find that the failure level (45%) maps into an overall GPA of 2.4. Satisfactory work occurs between 2.4 and 3.1, good work occurs between 3.1 and 3.7 and excellent work occurs above 3.7. This would indicate an average grade inflation of about 0.4 at the low end of the grade scale, decreasing to 0.3 at the high end. This is consistent with the estimated mean inflation rate of 0.4 since the 1960’s for public universities.

Grade inflation is also slightly correlated with major. Again, using the divisions outlined in §2 (natural sciences, social sciences, humanities, professional schools, undeclared), we found the natural sciences to only have a grade inflation rate of 0.2 at the low end, and none at the higher grades. The social sciences, professional schools and undeclared majors display grade inflation from 0.3 at low grades to 0.2 at the high end. The humanities suffered the most extreme grade inflation

| Major                | 'C' | 'B' | 'A' |
|----------------------|-----|-----|-----|
| Natural Sciences     | 2.2 | 3.1 | 3.5 |
| Social Sciences      | 2.3 | 3.2 | 3.7 |
| Humanities           | 2.6 | 3.5 | 3.9 |
| Professional Schools | 2.3 | 3.2 | 3.7 |
| Undeclared           | 2.3 | 3.2 | 3.7 |
of 0.6 at the low end to 0.4 at the upper grades (see Table 3). While one might argue that the extreme grade inflation in humanities is not due to changes in GPA, but low ASTR122 scores, remember the mean ASTR122 scores for all the majors (excluding the natural science majors) was identical. A similar trend was also detected in SAT scores versus GPA (Hsu & Schombert 2010), where the humanities displayed higher GPA’s per SAT bin compared to other majors.

While one could interpret this shift in objective scores to grade inflation of overall GPA, another possibility is that this change is due to course content depression. Every effort was made to keep the ASTR122 material at a college level, meaning that all the work assumes high school levels of math and science. Thus, the mismatch from ASTR122 score to overall GPA may reflect that, on average, most college courses have lowered the rigor of their subject material. Higher grades, then, are due to better student performance with lighter material, not due to lower grading standards. The reality of the day-to-day practicalities of teaching suggests that both effects come into play. A majority of instructors use grade curves, with little connection to any objective standard. We simply assume that admission standards produce a college-ready population of students and curve the grades to match that standard. In addition, instructors do wish to educate. Therefore, if the course content is not being absorbed, then lowering the content is a natural (and appropriate) response.

8. Conclusions

We can summarize our findings as the following:

- A series of unique conditions allowed four terms of introductory astronomy at the University of Oregon to be used to study college performance for the current student population. Those conditions are 1) highly repeatability course structure and material, 2) exams which are specifically designed with an objective grading scheme and 3) a homogeneous collection of students across a spectrum of majors.

- Total scores for ASTR122 were uniform from term to term with identical means and standard deviations. Natural science majors scores slightly higher than other majors. But, means and distributions were identical for social science, professional school, humanities and undeclared majors.

- Mapping ASTR122 total scores onto a 'F' (failure), 'C' satisfactory, 'B' (good) and 'A' (superior) grading scheme, we found that 29% of college students did not achieve a passing score in these classes. About 41% received satisfactory marks. Only 22% and 8% obtained good and superior marks.

- Total ASTR122 scores correlates well with intelligence factors such as SAT score. Total ASTR122 score also correlates extremely well with total college GPA.
• Mapping objective ASTR122 scores onto overall GPA provides a measure of global grade inflation. The resulting values by major are 0.2 for natural sciences majors, 0.3 for social sciences, professional schools and undeclared majors), 0.5 for humanities majors.

In general, the performance of non-science majors in an introductory course is less than optimal. This could be due to a number of factors, but all of them reduce to two possible scenarios: 1) the University admits student lacking the skills to perform basic college level tasks or, 2) students are able to perform college level work, but lack the motivation or time to do so. In other words, the students either have the skills or they do not. If they have the skills, then the problem becomes mostly one for the students to address, i.e., applying their skills to college level material. Grade inflation weakens the 'stick' for that positive reinforcement cycle. If they lack the skills, then our mission becomes more difficult, basically adapting our teaching to skill building rather than knowledge building (i.e., doing what the secondary schools failed to do).

As a quick test of the hypothesis on low student motivation, we introduced the use of clickers in the 2009 academic year. Clickers are the pedagogical toy-du-jour. Their usage is thought to increase student involvement in the course material and lecture attendance. Both of which should significantly improve student performance as measured by exam and quiz scores. To this end, we experimented on another introductory astronomy course (cosmology) over two terms, one with and one without the use of clicker technology.

Between these two courses, which taught identical material, class attendance increased from a mean of 40% per lecture to 85% for the clicker course. Student evaluations increased 30% for the clicker course. We consider these to be the two key elements in student involvement; positive student evaluations and high class attendance. However, Figure 6 displays the total scores for the two classes. Regardless of the significant improvement in the classroom environment, the exam and on-line quiz scores were identical for both terms (in fact, there was a slight increase in students with failing scores for the clicker class). This would indicate that the problem with lower student performance is ultimately tied to their ability and skill level, not motivation or social factors.

This type of study would not be possible without the development of network tools which can access and parse data webpages. Whether the data is in HTML or SQL format, the extraction of thousands of student records requires fairly intelligent, non-interactive scripts. These very tools were first invented for a knowledge based project funded by NASA’s AISR program. Their flexibility allows for a wide range of new avenues of inquiry across the fields of natural and social sciences, the kind of e-science demonstrated by ongoing efforts for the National Virtual Observatory.
Fig. 6.— Total course scores for an introductory astronomy class (cosmology) with and without the use of clickers. The was no significant difference in exam and on-line quiz scores.

black = no clickers, red = clickers