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hereby submit this original work as part of the requirements for the degree of:

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Assessing Genetic Literacy and the Impact of Instruction at the

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Assessing Genetic Literacy and the Impact of Instruction at the Undergraduate Level

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by

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ABSTRACT

As genetic knowledge and technologies continue to advance, it becomes increasingly important for individuals to have a broad understanding of basic genetics principles. Introductory biology and genetics courses provide an opportunity for increasing understanding of genetics concepts in thousands of students each year. This study is a continuation and expansion of efforts to assess student genetic literacy and critically evaluate undergraduate courses in genetics using the diagnostic Genetic Literacy Assessment Instrument (GLAI). A revised version of the GLAI was administered pre- and postcourse to 373 students enrolled in 10 introductory biology and genetics courses for nonscience and nursing majors at seven colleges and universities across the US. The content and reliability of the updated GLAI have been considered. Students averaged 57% on precourse evaluation, and postcourse scores improved modestly to an average of 67%. Student performance varied across different content areas, and prevalent misconceptions were highlighted on both pre- and postcourse evaluations. Course content and teaching methods were assessed via an instructor questionnaire and observations of classroom activity were conducted using the Reformed Teaching Observational Protocol. Analysis of the impact of these factors on student learning revealed that neither time spent on genetics concepts nor teaching methodologies systematically impacted student learning. Additional studies in genetics education are necessary to determine what aspects of instruction are most useful in improving learning and helping students overcome misconceptions.

Keywords: *assessment, biology education, genetics education, genetic literacy, undergraduate*

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INTRODUCTION

Genetic knowledge and technologies have continually grown and developed throughout the past several decades, and the implications for health care and public policy have become increasingly apparent (MILLER 1998, COLLINS AND MCKUSICK 2001, KOLSTO 2001). In order for individuals to act appropriately and effectively on newly emerging information and technology, they must have a sound grasp of basic genetic concepts (LANIE *et al.*2004). Genetic literacy can be defined as "sufficient knowledge and appreciation of genetics principles to allow informed decision-making for personal well-being and effective participation in social decisions on genetic issues" (BOWLING *et al.*2008a). This definition is similar to others in the literature which focus not only on the capacity to understand one's own social and health needs and interests in terms of genetic information and technology, but also the ability and power to act on that informed understanding (MCINERNEY 2002, JENNINGS 2004).

Although the importance of a genetically literate public has been emphasized at length, a number of studies have noted that misconceptions about basic genetic principles are common in the general public (LANIE *et al.*2004, MILLER *et al.*2006, CHRISTENSON *et al.*2010). When understanding of fundamental genetic concepts is lacking, the ability to make quality health care and public policy decisions is negatively affected. Improvements made in the genetic literacy of individuals could promote more informed and sounder personal and societal decision-making.

Science education is an opportunity to expose individuals to genetic principles and concepts, and ideally, genetics instruction should begin during early formal education. According to the National Science Education Standards, students in grade levels five through eight should begin to explore basic principles of reproduction and heredity. In grade levels nine through twelve, the molecular basis of heredity and biological evolution are introduced (NATIONAL RESEARCH COUNCIL 1996). By high school graduation, students should have a relatively broad understanding of basic genetic concepts. However, national standards do not guarantee that students will be able to understand genetic principles upon graduation. Despite the standards set for primary and secondary education, only 30% of twelfth grade students taking the 2000 National Assessment of Educational Progress were able to answer genetics questions correctly (O'SULLIVAN *et al.*2003). A large-scale analysis of student-generated essays addressing scientific arguments related to genetics also highlighted a number of errors and misconceptions regarding basic genetics concepts among high school students across the United States (MILLS SHAW *et al.*2008).

Postsecondary education provides an opportunity for individuals to potentially rectify misconceptions and inadequacies in genetic knowledge and expand their understanding of genetics beyond the basic standards set for high school students. College and university students obtaining degrees in the biological sciences are likely exposed to both introductory and upper level courses in genetics. However, only about 10-15% of the approximately two million individuals who obtain an associates or bachelors degree each year in the

US do so in the biological sciences, biomedical sciences, or health-related fields (NATIONAL CENTER FOR EDUCATION STATISTICS 2009). The remaining 85-90% of graduates may be exposed to genetic concepts in introductory general education courses in biology or genetics sometime during the course of postsecondary education. Undergraduate biology or genetics courses for non-science majors thus provide an excellent opportunity to improve genetic knowledge and literacy of individuals in the general population.

Recognizing the importance of a genetically literate public, and understanding that postsecondary courses for non-science majors are an opportunity for thousands of students to learn about genetics each year, Bowling and colleagues created the Genetic Literacy Assessment Instrument (GLAI) to evaluate undergraduate students' knowledge of basic genetic concepts and the effectiveness of undergraduate courses with a genetics component (BOWLING *et al.*2008a, 2008b). The GLAI is a 31-question, multiple choice assessment instrument geared expressly toward non-science major undergraduates. The items contained on the GLAI are based on central concepts in genetics that all undergraduate non-science majors should understand, as determined by an education subcommittee of the American Society of Human Genetics (HOTT *et al.*2002). The GLAI was evaluated and shown to be a reliable and valid tool for measuring genetic literacy in undergraduate students (BOWLING *et al.*2008a). The GLAI is not the only available instrument which evaluates genetic knowledge; the Genetics Concept Assessment tool, for example, has been used to assess student learning outcomes in undergraduate genetics courses (SMITH *et al.*2008). Unlike items contained on the GLAI, however, questions on the Genetics Concept Assessment are based largely on learning goals developed for a majors' genetics course at the University of Colorado, Boulder (SMITH *et al.*2008). To our knowledge, the GLAI is currently the only validated assessment tool for assessing genetic literacy specifically in undergraduate non-science majors.

Outside of genetics, evaluation of student knowledge and the impact of introductory courses has been a significant area of focus in several other branches of science education. Many "concept inventories," similar in nature to the GLAI, have been developed to evaluate student knowledge of a particular set of concepts before and after instruction (MULFORD AND ROBINSON 2002, GARVIN-DOXAS AND KLYMKOWSKY 2007). One such instrument, the Force Concept Inventory (FCI) in physics (HESTENES *et al.*1992), has been a critical tool in the reformation of physics education (HAKE 1998). By evaluating changes in knowledge and understanding of students enrolled in introductory courses, researchers in multiple disciplines have attempted to identify factors that influence student learning, and make suggestions for improving current science education.

During the 2006-2007 academic year, the Genetic Literacy Assessment Instrument was administered to over 300 students enrolled in introductory biology and genetics courses at a variety of colleges and universities (BOWLING *et al.*2008b). In addition to students' genetic literacy, course content and teaching methodologies were evaluated in this study. Teaching methodology has previously received a considerable amount of attention in the evaluation of science education. A number of studies have shown that utilization of interactive methods in undergraduate science courses leads to improved student performance and larger gains in knowledge compared to use of more traditional, didactic teaching methods (HAKE 1998, NATIONAL RESEARCH COUNCIL 2003, WILKE 2006). A significant correlation between more “reformed,” interactive teaching and gain in student knowledge was also identified during the 2006-2007 administration of the GLAI. This study also found that the quantity of time spent on genetics content did not seem to have a significant impact on student learning (BOWLING *et al.*2008a).

The originators of the GLAI recognized that this inventory is not a static instrument; as with any assessment tool, it is critical to regularly evaluate and assess the usefulness of the GLAI. While the GLAI was found to be a reliable indicator of genetic literacy, needs for improvement in some instrument items were recognized (BOWLING *et al.*2008a). Five questions on the original version of the GLAI were identified as poor discriminators; success on these items did not necessarily predict success on the GLAI as a whole, and revision of these questions was recommended. The authors also recognized that administration of the GLAI to more students could garner greater insights into student perceptions so that instrument items could be clarified and revised accordingly (BOWLING *et al.*2008a).

The 2008 study by Bowling and colleagues was the first to consider both teaching methods and time devoted to specific genetic content areas in evaluating student literacy with a standardized assessment tool. The present study seeks to continue and expand upon these efforts to critically evaluate genetics education at the undergraduate level. Through the implementation and evaluation of changes to the GLAI, and the expansion of student and course data collection to institutions across the country, we hope to deepen understanding of how instruction might affect student learning in genetics. Part of these expansion efforts includes utilization of the GLAI to assess introductory genetics courses for undergraduate nursing majors. Since the effort to improve genetics education for nurses began over 30 years ago, relatively little has been done to evaluate the genetic knowledge of nursing students (BURKE AND KIRK 2006). Using a validated tool to assess knowledge and the impact of introductory biology and genetics courses for non-science and nursing majors should lead to suggestions for improving genetics education. Providing more effective genetics education at the undergraduate level could enhance students' abilities to understand and utilize genetic information in personal and social decision-making.

METHODS

Study Design: Many of the methods utilized in this study were previously described by Bowling and colleagues in 2008. This study was designed as an observational cross sectional study of instructors and an observational longitudinal study of students. There was no manipulation of setting or of study subjects, and all instruments and procedures were approved by the institutional review board of each participating institution. Participants were the instructors of introductory biology or genetics courses for undergraduate non-biology majors or undergraduate nursing students. Participants were recruited and self-selected from a convenience sample, which included previous participants in GLAI-related studies (BOWLING *et al.* 2008a, 2008b), individuals who contacted the primary investigator of the 2008 studies with an interest in utilizing the GLAI, participants of a 2008 American Society of Human Genetics (ASHG) conference on undergraduate education, and members of the International Society of Nurses in Genetics (ISONG) and NIH Genetic/Genomic Nursing Competency Initiative Listserv. Approximately 200 potential instructors were contacted to participate. Ten instructors of eleven courses (four introductory biology courses for non-science majors, six introductory genetics courses for non-science majors, and one introductory genetics course for nursing majors) at seven widely dispersed institutions were eligible and agreed to take part in the study. Approximately 640 students enrolled in the eleven courses during the 2008-2009 and 2009-2010 academic year were invited to participate; 526 students completed the precourse GLAI, and 482 students completed the post-course GLAI; 412 students completed both the pre- and post-course assessments.

The Genetic Literacy Assessment Instrument Version 2 (GLAI V2): The GLAI is a 31 question multiple choice assessment tool which covers six major content areas central to basic genetic knowledge (HOTT *et al.* 2002). The GLAI was developed and validated by Bowling and colleagues (BOWLING *et al.* 2008a) and has been previously used to assess undergraduate student literacy (BOWLING *et al.* 2008b). Six questions from the original GLAI were identified as needing improvement (BOWLING *et al.* 2008a) and underwent revision by the authors in the development of the GLAI Version 2 (V2). The GLAI V2 contains five questions (Q1, Q2, Q5, Q11, Q13, Q14) which were significantly changed and one question (Q24) which was slightly modified from the original version of the GLAI.

The GLAI V2 was administered to students through the online survey program SurveyMonkey® both pre-course (during the first week of class) and post-course (during the last week of class). Students completed the assessment individually, outside of scheduled class time. In addition to the pre- and post-course assessments, one instructor included thirty questions from the GLAI V2 on the final exam for the course (course E).

Instructor and Course Data: Data on instructor teaching methods were collected through classroom observations using the Reformed Teaching Observation Protocol (RTOP) (MACISAAC AND FALCONER 2002) for three of eleven courses. This instrument is a standardized way to measure reformed teaching, which includes the use of inquiry-based activities and other constructivist teaching approaches. The RTOP consists of 25 statements which can be evaluated on a scale of 1-4. Overall scores range from 0-100, with more reformed courses scoring higher. The RTOP and its utilization were previously described by Bowling and colleagues (2008b). Three observers, trained to use the RTOP via an online tutorial, observed two sessions of each of the three courses. The scores of the observers were averaged to determine the level of reformed teaching for each course.

Information regarding the instructors, genetics content covered, and teaching methods utilized was collected through a questionnaire completed by instructors. The instructor questionnaire is based on a questionnaire used previously by Bowling and colleagues (2008b), but contains additions and revisions based on input and feedback from a number of instructors of biology and genetics courses. The questionnaire was administered to instructors using the online survey program SurveyMonkey® during the final week of the quarter or semester. Ten of eleven participating instructors completed the instructor questionnaire.

Data Analysis: The data of students who were under 18 years old at the time of the study were not included in analyses. Data from students who self-identified as a biology or related major (premedicine, environmental science, neuroscience, or molecular biology) were also excluded from analyses. Additionally, data from those students who did not achieve greater than 20% on the post-course assessment, a score which is equivalent to guessing, were excluded. One course (an introductory genetics course) was not considered in analyses due to limited student participation; only five of 32 students enrolled this course completed both the pre- and post-course GLAI V2. Data from 373 students enrolled in ten courses were analyzed.

Instrument Assessment: Item analyses conducted for the GLAI V2 were similar to those carried out by Bowling and colleagues in their evaluation of the original GLAI (BOWLING *et al.* 2008a). Item difficulty, defined as the proportion of students answering the question correctly (KAPLAN AND SACCUZZO 1997) was calculated for each question on the pre-course administration of the GLAI V2. Item discrimination, defined as the extent to which success on that question corresponds to success on the instrument as whole (NUNNALLY AND BERNSTEIN 1994), was also calculated for each question on the GLAI V2. Discrimination values were determined by calculating a biserial correlation between the performance on a particular item and the performance on the instrument as a whole (HENRYSSON 1971). Students' selection of distractors, the incorrect answer options presented for each question, was analyzed for both the pre- and post-course GLAI V2 by determining the percent of students responding to each answer option (A-E) for all questions. Internal consistency reliability, the degree of consistency between instrument items, was assessed by calculating Cronbach's α for both pre- and post-course student scores. A reliability coefficient >0.70 is generally considered acceptable (FIELD 2009).

Student and Course Data: Analyses of student and course data were also similar to those conducted by Bowling and colleagues in their study of genetic literacy and the impact of undergraduate courses on student knowledge (BOWLING *et al.* 2008b). In the present study, pre- and post-course GLAI V2 scores were compared using a one-tailed, paired *t*-test to determine the impact of the courses on GLAI V2 achievement. Cohen's effect size *d*, a scale-free measure of the difference between two group means, was calculated for each course in which a significant difference was found between and pre- and post-course scores (COHEN 1988). For course E, post-course GLAI V2 scores and scores for the GLAI V2 questions included on the course's final exam were also compared using a one-tailed, paired *t*-test to determine whether students performed differently on the ungraded assessment versus the graded final exam.

Normalized gain (NG), popularized by Hake as an objective measure of student learning, is defined as the ratio of actual gain (post-course percentage minus pre-course percentage) to the maximum gain possible (100 minus pre-course percentage) (HAKE 1998). NG was calculated for each student and then averaged within each course. Average NG within each course was used as the dependent variable in a linear regression analysis with RTOP scores and course content to assess whether teaching methods and time spent on genetics content have a significant impact on student learning. A simple linear regression was also conducted to determine whether instructor-reported reported teaching methods (class time spent lecturing) have an impact on student learning.

RESULTS

Of 640 student invited to participate in this study, 412 students completed both the pre- and postcourse assessments. A total of 39 students were excluded from data analyses; six students less than 18 years old were excluded, as were 23 students who self-identified as a biology or related major. Additionally, six students achieved ≤ 20% on the postcourse GLAI V2 and were not included in data analyses. One course was also excluded from analyses because of limited student participation; only five of 32 students completed both the pre- and postcourse assessment in this course. A total of 373 students enrolled in 10 courses completed both the pre- and postcourse GLAI V2, met inclusion criteria, and were included in data analyses for this study. Courses differed in participation rates, but over 54% of students participated in the study across all courses (table 1). Full demographic data were available for eight of the 10 courses. In these eight courses, the makeup of students participating in the study was consistent with that of students enrolled in the courses. Females comprised 72% of enrolled students and 75% of study participants. In addition, the proportion of students in each class level (freshman, sophomore, junior, senior) enrolled in the courses was similar to the proportion of student participants in each of those class levels.

Eight of the nine instructors of the 10 courses from which data were analyzed in this study completed the postcourse instructor questionnaire in part or in whole.

Instrument Assessment: The percent of students responding correctly to each item (item difficulty) on the GLAI V2 ranged from 26.8 to 90.1 on the precourse assessment. Average item difficulty for the precourse assessment as a whole was 57.1 (table 2). Two items, Q6 and Q24, were particularly difficult for students on the precourse administration of the GLAI V2 (figure 1). These questions pertained to the nature of the genetic material and genetic variation among humans. Less that 30% of students were able to answer these items correctly. Conversely, over 90% of students were able to correctly answer item Q12 (figure 1), which addresses genetic variations which result in disease.

All distractors on the GLAI V2 were selected at least once, with ranges of 0.8 to 38.3% on the precourse assessment and 1.1 to 26.5% on the postcourse assessment. Only one distractor on the precourse administration was selected more frequently than the correct answer (item Q25, figure 1). No distractors were selected more frequently than the correct answer on the postcourse GLAI V2. To protect the integrity of the GLAI V2, full pre- and postcourse distractor data are not presented here, but are available upon request.

The extent to which success on each individual item corresponded to overall success on the GLAI V2 (item discrimination) varied from 0.25 to 0.74 for precourse items. Average discrimination of all items was 0.52 (table 2). Only two items, Q4 and Q5, had discrimination values less than 0.30, the level at which an item is considered a “good” discriminator.

In terms of internal consistency reliability, Cronbach's alpha was measured at 0.82 for the precourse administration and 0.87 for the postcourse administration of the GLAI V2.

For course E, student performance on 30 questions from the postcourse GLAI V2 was compared to performance on those same 30 questions on the course's final examination. A one-tailed, paired *t*-test showed student achievement on the postcourse GLAI V2 to be significantly lower than achievement on the course final examination (degrees of freedom = 26, t = 3.534, p = 0.001).

Impact of Courses: Courses affected the students' scores to varying degrees (figure 2), but for all courses, pre- and postcourse GLAI V2 scores averaged 57.1% and 65.7% respectively. Course J, an introductory genetics course for nursing majors, and course I, an introductory genetics course for nonscience majors, showed the highest precourse averages (table 1). Overall, pre- and postcourse GLAI V2 scores were higher in introductory genetics courses for nonscience or nursing majors than introductory biology courses (table 1). Normalized gain (NG), the standardized measure of learning calculated for each student, also varied across the courses, ranging from 0.06 to 0.45. Average NG across all courses was 0.19. Course I, the course in which the precourse average was highest, was also the course in which students showed the highest postcourse average and the highest average NG. Course J, which also had a high precourse average, showed the smallest gain in student knowledge. Overall NG was generally higher in introductory genetics courses than introductory biology courses.

Based on a one-tailed, paired *t*-test, pre- and postcourse GLAI V2 scores were significantly different ($p < 0.05$) within each course (table 3). Cohen's effect size *d* values indicate that six courses had medium or large effects (Cohen's $d > 0.5$) on student achievement on the GLAI V2 (table 3).

Instructors reported spending various amounts of class time on the six specific content areas covered on the GLAI V2 (table 4). Transmission genetics was the topic on which instructors reported spending the highest average number of academic hours during the quarter or semester. Transmission genetics was also the area in which the most improvement in student scores was seen from pre- to postcourse. Instructors reported spending far less class time on topics such as gene expression and gene regulation. Nonetheless, students did show improved achievement on questions pertaining to these topics (table 4). Students showed the smallest gains in the content areas of evolution and genetics and society; pre- and postcourse averages in these content areas differed by only 4.1 % (table 4).

The overall time spent on genetics content also varied among the nine courses for which data were available, with a range of 14 to 36 hours and an average of 24.7 hours reported by instructors (table 1). Although there was an apparent trend toward higher normalized gain with overall increased time spent on genetics, linear regression analysis for nine courses showed that time spent on genetics did not have a significant effect ($p < 0.05$) on normalized gain (R^2 = 0.415, slope=0.013, p = 0.061).

Seven of nine responding instructors reported that at least 50% of class time was devoted to didactic lecture (table 1). Linear regression analysis showed no significant relationship between percent of class time spent lecturing and normalized gain (R^2= 0.026, slope = -0.007, p = 0.678). Only three courses (B, E, and J) were available for observation and assessment using the Reformed Teaching and Observation Protocol (RTOP) (table 1). RTOP scores for these three courses ranged from 40.9 to 60.2. Linear regression showed no significant effect of RTOP scores on normalized gain (R^2= 0.227, slope =0.0005, p = 0.684).

DISCUSSION

This study was designed to continue and expand upon efforts initiated by Bowling and colleagues to critically evaluate students' genetic literacy and genetics education at the undergraduate level. Through the utilization of a revised Genetic Literacy Assessment Instrument, we have recognized deficits in student knowledge of basic genetic concepts, and considered factors which may play a role in student learning.

Instrument Assessment: The Genetic Literacy Assessment Instrument (GLAI) was created in 2008 to assess the genetic literacy of undergraduate students (BOWLING *et al.* 2008a). The GLAI has been shown to be a reliable and valid tool in evaluating several samples of undergraduate students, and it has also been useful in assessing the impact of introductory biology and genetics courses for undergraduates. Revisions to the GLAI implemented in the creation of the GLAI Version 2 (V2) have improved the instrument; item analysis indicates that the GLAI V2 meets or exceeds current standards set for the evaluation of assessment instruments.

A successful assessment instrument must contain questions of variable difficulty in order to discriminate among students with varying levels of knowledge (NUNNALLY AND BERNSTEIN 1994), but for multiple-choice questions with five answer choices, item difficulty, the proportion of students answering that question correctly, should approach 60% (KAPLAN AND SACUZZO 1997). With an average item difficulty of 57%, the GLAI V2 shows improvement compared to the original version of the GLAI, where average item difficulty was 43% (BOWLING *et al.* 2008a).

The range of item difficulty for the 31 questions on the GLAI V2 was 26.8-90.1% for precourse administration, which indicates that some basic concepts in genetics are understood by students even before entering an introductory biology or genetics courses. Over 90% of students were able to correctly answer GLAI V2 item 12, which addresses complex inheritance in the context of BRCA gene mutations. Some concepts were, however, more challenging for students. GLAI V2 item 24, which addresses genetic variation among ethnic groups in the context of human evolution, was the most difficult question on the precourse administration of the GLAI V2. Interestingly, a study of public understanding of basic genetics revealed that a similar misconception regarding genetic determinants of race was common among men and women in the United States (CHRISTENSON *et al.* 2010). These results show that precourse administration of the GLAI V2 can help shed light on prevalent misconceptions of basic genetic concepts. This information would be extremely useful to instructors, who could tailor course content and instruction to address those issues which seem to be most difficult for students. Post course data from the GLAI V2 can also be useful in planning revisions for future courses to better address misconceptions that student retain after course completion.

Overall high item discrimination values, which refer to how well success on a specific item predicts overall success on the whole assessment (KAPLAN AND SACCUZZO 1997), show that the GLAI V2 is capable of differentiating between students who understand the material well and students who do not. Point biserial values used to assess discrimination should ideally approach one, but values greater than 0.30 are considered desirable (NUNNALLY AND BERNSTEIN 1994, KAPLAN AND SACCUZZO 1997). Discrimination values on the original GLAI ranged from 0.03 to 0.69, and two items, with discrimination values <0.05, were considered very poor discriminators (BOWLING *et al.* 2008a). Analysis of the GLAI V2 shows improved item discrimination compared to the original version of the tool. Discrimination values on the updated version of the tool ranged from 0.25 to 0.74 and averaged 0.52. The GLAI V2 contained only two items (questions four and five) with less than excellent discrimination values based on the biserial correlation (< 0.30).

The GLAI V2, like the original GLAI, has excellent internal consistency. Cronbach α-values of 0.81 on precourse administration and 0.87 on postcourse administration of the GLAI V2 suggest that the instrument reliably measures the underlying construct of genetic literacy.

Analysis of precourse responses showed that the distractors on the GLAI V2 are effective in determining which misconception the student might use as the basis for their answer. While some distractors were chosen less frequently than others, all distractors were chosen by at least 1% of respondents, indicating that all answer choices were considered plausible by some students. In the case of item 25, which pertains to gene expression, a distractor was chosen more frequently than the correct answer. While 38% of students incorrectly indicated that genes code for DNA, only 32% of students recognized that genes code for proteins which are responsible for individual traits. This suggests that a portion of undergraduate students may have a fundamental misunderstanding of the relationship between DNA, genes, and proteins before entering postsecondary courses in biology or genetics.

Impact of Courses: Although postcourse GLAI V2 scores were significantly improved compared to precourse scores in all courses, students showed an overall modest gain in knowledge. Similarly small gains in student knowledge were observed when the original version of the GLAI was administered to undergraduate nonscience majors; normalized gain in this study ranged from 0.01 to 0.25 for six courses (BOWLING *et al.* 2008b). Modest pre- to postcourse changes were also seen following introductory courses in other subject areas where concept inventories were used to evaluate gains in student knowledge (HAKE 1998, MULFORD AND ROBINSON 2002, COLETTA AND PHILLIPS 2005).

Because of low precourse scores and modest postcourse score improvements noted in this and previous studies, concern has been raised that students may not complete ungraded assessments to the best of their ability. A comparison of postcourse GLAI V2 scores and the final exam completed by students enrolled in course E suggests this might be the case for some students. Students scored significantly higher on the 30 GLAI V2 questions included on the final exam than when they completed the postcourse assessment. It should be noted that this comparison was only made for a limited number of students (n = 27). Additionally, it is worth considering that after the pre- and postcourse assessments, the final exam was the students' third time being exposed to the GLAI V2 questions, and this could have contributed to improved performance. The fact that students likely studied and reviewed course materials in preparation for the final exam must also be taken in to consideration. All student responses to the pre- and postcourse GLAI V2 were monitored for patterns which might indicate insincerity (e.g. selecting the same letter choice for all questions) but none such patterns were observed. The issue of student sincerity has been considered in previous studies, most notably in an evaluation of the Force Concept Inventory (HENDERSON 2002). In this study of 500 students taking the Force Concept Inventory, little difference was noted between graded and graded FCI scores, and giving the pre-test did not seem to affect student achievement on the post-test FCI (HENDERSON 2002). Nonetheless, student sincerity remains a concern in the use of ungraded assessments of student knowledge, and future investigators should remain cognizant of this potentially complicating factor.

Although precourse GLAI V2 scores were relatively low overall, two courses, I and J, showed precourse averages above 65% (table 1). Interestingly, of the 10 courses surveyed, normalized gain was highest in course I and lowest in course J. Course I is an introductory level genetics course at a small, private liberal arts institution. The course is designed for non-science majors, but based on instructor report, a number of upper level biology majors take the course as an elective. Any student who self-designated as a biology major was not included in this study, but one explanation for high postcourse scores in the nonscience major students could be that students benefitted from interaction with other students already knowledgeable in genetics. Course J consists of three separate sections of a course for undergraduate nursing majors; because all three sections share the same instructor and course content, these sections were combined for the purpose of analysis. Relevant to the high precourse scores noted in course J, students had completed one three-hour lecture before taking the precourse assessment since the class meets only once per week for three hours. This may have artificially raised precourse scores, and thereby affected normalized gain calculations. Additionally, we must consider that undergraduate nursing students may be exposed to genetics content in other courses that may contribute to higher precourse scores than nonscience majors. The instructor of course J reported that prior to the introductory genetics course, nursing students at this institution take only one course specifically in biology (anatomy and physiology) and that this course involves little to no genetics instruction.

Student performance varied across the six different content areas addressed on the GLAI V2 (table 4). The percentage of students able to correctly answer questions pertaining to evolution and genetic variation was low on both pre- and postcourse assessment. Similarly, students performed poorly on questions focused on gene expression on the precourse assessment, although improvements from pre- to postcourse were relatively high in this content area. On average, instructors reported spending only 0.5 more hours of class time focused on gene expression (2.7 hours) versus evolution (2.2 hours). Based on this observation, time spent on specific content does not seem to systematically explain differences in student knowledge gained in those areas, although the material covered within these content areas may not have consistently reflected the concepts being asked on the GLAI V2. Linear correlation analysis also showed that overall time spent on genetics content did not have a statistically significant impact on normalized gain across the nine courses with available data. Although gain within each content area was not directly compared to the number of hours spent on that content area, these results suggest that something other than time spent on a particular concept may have more important impacts on student learning.

Of the many factors which likely contribute to and affect student learning, teaching methodology has been the focus of numerous studies. Research utilizing the Force Concept Inventory (FCI) showed that introductory physics courses in which instructors utilized interactive, engaging methods resulted in higher gains in student knowledge than courses in which more traditional teaching methods were utilized (HAKE 1998). The Reformed Teaching Observational Protocol (RTOP) tool has been used in conjunction with concept inventories to identify the impact of teaching methods on student learning. Studies in mathematics and the physical and biological sciences have shown a significant correlation between RTOP scores and normalized gain (LAWSON *et al.* 2002, MACISAAC AND FALCONER 2002). Importantly, previous research using the original GLAI showed a small but significant correlation between RTOP scores and student gain, but not quantity of time spent on genetics (BOWLING *et al.* 2008b).

In the present study, multiple regression analysis did not show RTOP scores or time spent on genetics content to have a significant impact on student gain in this study. Due to logistics and limited availability of trained observers, observations were made for only three courses. Three individuals completed two observations for each of the three courses. The range of RTOP scores was limited, with a maximum score of 60.2. Based on previous studies in which RTOP scores greater than 70 yielded high normalized gains (MACISAAC AND FALCONER 2002), Bowling and colleagues suggested a possible threshold for RTOP scores, such that knowledge gained is much greater in significantly reformed courses compared to moderately or slightly reformed courses (BOWLING *et al.* 2008b). Weak correlations between RTOP scores, time spent on genetics content, and normalized gain seen in this study are difficult to interpret based on so few data points and a limited range of scores.

In addition to RTOP scores, this study also considered percent of class time spent on lecture in evaluating teaching methodologies. Self-reports of teaching methods utilized are not equivalent to or intended to be a substitute for RTOP scores, but instructor reports on teaching methods have been shown to provide a reasonable estimate of how class time was used (BOWLING *et al.* 2007). Data available for nine courses indicates that most instructors spend a majority of class time lecturing. Regression analysis did not show a significant relationship between time spent lecturing and normalized gain. Although data from most courses were available for this assessment, the fact that courses were primarily lecture-based limits the interpretation of this analysis.

Utilization of an assessment tool like the GLAI V2 promotes critical evaluation of student knowledge and the ways in which courses impact learning. The GLAI V2 has been shown to be a reliable tool for accurately assessing knowledge of basic genetic concepts, and the GLAI V2 can be helpful in identifying student misconceptions both before and after instruction. Pre- and postcourse assessments of student knowledge using the GLAI V2 can be used to determining what aspects of instruction are useful in helping students overcome those misconceptions. Course content and teaching methodologies are only two of the many factors that may contribute to student learning. Efforts should be made to continue critical evaluation of genetics knowledge and learning at the undergraduate level so that opportunities for students to learn about genetics and improve genetic literacy can be maximized.

Anyone who is interested in using the GLAI V2 in their own course or collaborating in continued research in this area is encouraged to contact the authors.

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APPENDIX

TABLE 1

Description of courses, participants, and GLAI V2 mean scores

	Course									
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Class size										
Completed course	83	37	38	95	50	45	97	17	36	190
Participated in study	46	17	15	38	30	31	56	11	13	116
Percentage participated	55.4	45.9	39.5	40.0	60.0	68.9	57.7	64.7	36.1	61.1
Course information										
Course type	Introductory Biology	Introductory Biology	Introductory Biology	Introductory Biology	Introductory Genetics	Introductory Genetics	Introductory Genetics	Introductory Genetics	Introductory Genetics	Genetics for Nurses
Time spent on genetics content (hours)	20	20	14	22	27	-	36	31.25	28	24
Percent lecture	60	60	25	100	50	-	100	80	20	70
Mean RTOP score	-	60.2	-	-	47.8	-	-	-	-	40.9
GLAI mean scores										
Precourse	46.8	47.2	51.2	46.5	54.7	45.5	63.2	51.3	75.2	66.1
Postcourse	60.0	56.2	61.1	53.6	65.3	54.0	74.4	69.8	86.1	70.4
Normalized gain	0.25	0.18	0.16	0.13	0.25	0.14	0.34	0.41	0.45	0.06

TABLE 2

Item difficulty and discrimination for precourse GLAI V2 items

Question	Item difficulty	Item discrimination
Q1	80.7	0.38
Q2	70.8	0.65
Q3	59.8	0.46
Q4	42.1	0.25
Q5	53.1	0.25
Q6	29.2	0.37
Q7	68.9	0.49
Q8	50.7	0.55
Q9	64.6	0.52
Q10	77.2	0.74
Q11	71.0	0.58
Q12	90.1	0.61
Q13	69.7	0.56
Q14	57.6	0.42
Q15	41.8	0.67
Q16	63.3	0.56
Q17	79.6	0.64
Q18	56.3	0.55
Q19	34.0	0.55
Q20	68.1	0.67
Q21	44.2	0.39
Q22	39.1	0.49
Q23	60.1	0.54
Q24	26.8	0.61
Q25	31.9	0.57
Q26	35.7	0.40
Q27	50.1	0.60
Q28	54.7	0.52
Q29	80.4	0.58
Q30	75.6	0.45
Q31	42.4	0.46

TABLE 3

***t*-test comparisons of pre- and postcourse GLAI V2 scores**

Course	Degrees of freedom	*t*	*p* (one-tailed)	Cohen's *d*
A	45	5.757	<0.01	0.90
B	16	2.009	0.03	0.41
C	14	2.924	<0.01	0.60
D	37	2.583	<0.01	0.37
E	29	3.845	<0.01	0.60
F	30	3.258	<0.01	0.44
G	55	8.869	<0.01	0.73
H	10	3.798	<0.01	0.91
I	12	4.754	<0.01	0.94
J	115	2.715	<0.01	0.24

TABLE 4

Course time spent and percentage of students answering GLAI V2 items correctly in each of six content areas.

Content area	Nature of the genetic material	Transmission	Gene expression	Gene regulation	Evolution	Genetics and society
Average time (hours)	3.0	7.8	2.7	1.4	2.2	6.5
Range of time (hours)	2-5	1.5-12	1-7.5	0-5	0-4	1-21
Precourse mean	57.9	57.1	49.1	67.4	40.0	65.7
Postcourse mean	66.5	70.8	61.6	75.2	44.1	69.8

FIGURE 1

Example questions from the GLAI V2 (asterisk indicates correct answer, italics indicates answer chosen most frequently on precourse administration) and percent of students responding correctly on pre- and postcourse administration.

6. Which of the following is INCORRECT regarding meiosis? (29%, 57%)
a. It occurs only in species of organism that have sexual reproduction.
b. It halves the chromosome number in reproductive cells.
c. It provides for genetic variation in the offspring.
**d. It occurs in most body cells at some time during the life of the individual.*
e. It keeps the chromosome number constant from generation to generation.

12. A woman has been told she carries a mutation associated with breast cancer. How does this influence her likelihood of developing breast cancer? (90%, 90%)
a. Her risk will be no different from any other healthy woman.
b. She will likely not get breast cancer.
**c. She is at an increased risk for breast cancer.*
d. She will definitely get breast cancer.
e. She already has breast cancer since she carries the mutated gene.

24. Which of the following is INCORRECT regarding the genetic differences among ethnic groups? (27%, 39%)
a. There is much more genetic variation within ethnic groups than among them.
b. Differences in appearance represent only minor genetic differences among ethnic groups.
c. Genetic diseases, such as sickle cell disease, have an increased prevalence within certain ethnic groups.
d. The DNA sequence is more than 99% similar among all humans.
**e. Genetic differences responsible for skin color represent a substantial portion of the human genome.*

25. What is the relationship between genes and traits expressed in individuals? (32%, 55%)
a. Genes code for DNA, which is responsible for individual traits.
*b. Genes code for proteins, which are responsible for individual traits.
c. Genes code for chromosomes, which are responsible for individual traits.
d. Genes code for carbohydrates, which are responsible for individual traits.
e. The environment rather than genes is primarily responsible for individual traits.

FIGURE 2. Mean pre- and postcourse GLAI V2 scores by course. Error bars indicate standard error at the 95 percent confidence interval.