Online Courses Provide Robust Learning Gains and Improve Learner Confidence in the Foundational Biomedical Sciences

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Abstract
The early stages of medical school involve education in a number of foundational biomedical sciences including genetics, immunology, and physiology. However, students entering medical school may have widely varying levels of background in these areas due to differences in the availability and quality of prior education on these topics. Even students who have recently taken formal courses in these subjects may not feel confident in their level of preparation, leading to anxiety for early-stage medical students. These differences can make it difficult for instructors to create meaningful learning experiences that are appropriate for all students. Additionally, actual or perceived differences in preparation may lead fewer students from diverse backgrounds to apply to medical school. Therefore, creating an efficient and scalable way to increase students’ knowledge and confidence in these topics addresses an important need for many medical schools. We recorded pre- and post-course quiz scores for 9790 individuals who completed HMX online courses, developed in accordance with evidence-based learning practices and covering the fundamentals of biochemistry, genetics, immunology, pharmacology, and physiology. Each question was accompanied by a Likert scale question to assess the learner’s confidence in their answer. Learners’ median post-course quiz performance and self-assessed confidence significantly increased relative to pre-course quiz performance for each course. Improvements were consistent across US-based medical schools, non-US medical schools, and course runs open to the public. This indicates that online courses created using evidence-based learning practices can lead to significant increases in knowledge and confidence for many learners, helping prepare them for further medical education.

Keywords Online learning · Assessment · Self-assessment · Biomedical sciences · Learning outcomes

Introduction

Successful completion of medical training requires a fundamental knowledge of subjects such as physiology, biochemistry, and immunology [1]. Generally, medical students are required to take courses in these foundational medical sciences early in their training to ensure that they have the knowledge necessary to complete more advanced courses and clinical rotations later on. However, students come into medical school with a wide range of backgrounds and preparation and may need additional help to get up to speed as they start medical school [1]. These differences in preparation can be a significant factor in determining who enters medical school and who succeeds in completing medical training. For instance, poor performance in early pre-med courses as undergraduates can greatly decrease the likelihood of individuals from underrepresented minority groups completing the pre-med course of study [2, 3]. Therefore, differences in preparation and learner confidence have strong implications for efforts to increase diversity in medical school cohorts.

In addition to knowledge of a subject, the ability to assess one’s own knowledge is important for success in the medical field [4]. As learners increase in knowledge, their ability to assess their level of knowledge also increases, helping them to direct their future studies and identify gaps that need to be filled [5]. Therefore, increasing learner metacognition is an important goal of any course. In order for online courses to be a viable educational tool, they must not only increase learner knowledge but also assist the learners in their ability to assess their own learning. One way to measure this is by measuring learner self-confidence in their answers. Individuals with a high level of metacognition are able to accurately determine the likelihood that their answer is correct, and it is important to determine whether online courses facilitate this ability.

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Online courses offer an opportunity to address these issues by improving preparation in the foundational biomedical sciences and increasing awareness of and confidence in learners’ knowledge and approach to learning [6].

In recent years, the learning landscape has seen incredible growth in the online space [7]. Massive Open Online Courses (MOOCs) led the way, but other online learning approaches have led to a variety of options for learners [8]. Additionally, the use of entirely or partially online courses increased greatly in countries around the world during the COVID-19 pandemic, and online learning has become embedded in curricula [9–11]. A variety of formats exist for online learning, including MOOCs, small private online courses, hybrid courses that include both online and in-person learning, and informal online learning, among others. Each of these modalities has advantages and disadvantages depending on the goals of the learner and may be better suited to specific circumstances and types of learners. Many proponents of online learning tout the availability of high quality education, regardless of learners’ locations, and the democratization of learning as strong advantages of online learning. However, the ability of online courses to consistently lead to significant learning gains is still debated. Early studies of MOOCs often focused on learner completion rates, rather than actual learning, and some educators remain unconvinced that online learning is able to live up to its high expectation and provide comparable learning benefits to more traditional, in-person teaching [12].

In this study, we aimed to determine whether the completion of fully online courses in foundational medical sciences created using strongly evidence-based learning practices led to robust gains in knowledge on those subjects by comparing learners’ performances on a pre-course quiz to their performance on a post-course quiz. Examples of these evidenced-based learning practices include use of short videos [13], real-world examples [14], spaced repetition [15], interleaving [16], frequent low-stakes formative assessments [17, 18], and others. Additionally, we compared learners’ self-confidence on the pre- and post-course quizzes in order to measure changes in confidence that accompany any observed change in knowledge. The goal was to quantify the changes in knowledge and self-confidence produced by completion of online courses in a number of foundational medical sciences and determine whether online courses represent a viable form of preparation in these areas.

Methods

Data Sources

The study consisted of a group of 21,039 total learners who participated in a series of fully online courses in the fundamental biomedical sciences. The available courses were foundational courses in biochemistry, genetics, immunology, pharmacology, and physiology. These learners were divided between a number of different “cohorts,” or instances of the courses. Cohorts belonged to three different groups: US-based medical schools, non-US-based medical schools, and public course runs. US-based and non-US-based medical school cohorts consisted of only learners from those schools, with the vast majority either about to enter medical school or at first-year level and not having yet taken the topics examined in this study as part of their medical school curriculum. Public course runs (PCRs) were open to individuals who applied and were accepted. The five courses were released at different times between 2017 and 2020 and each course has had different numbers of cohorts, leading to the inclusion of 3–16 separate cohorts per course and group in this dataset. Learners who took at least 85% of the assessment questions and attempted the final exam, as indicated by a non-zero score, were considered to have “completed” the course. All learners who had completed each course were selected for further study. These learners were then divided into learners who had submitted both the pre- and post-course quiz and those that had not. The post-course quiz had to be taken after the pre-course quiz in order for the post-course quiz score to be considered, and if a learner attempted the pre- or post-course quiz more than once, only the first attempt was recorded. Similarly, if a learner enrolled in subsequent iterations of a course, only their first attempt was included in the study. A summary of the learners included in the study is presented as Table 1. Demographic information was not collected for learners. The majority of learners in the medical school cohorts had not yet begun medical school or were in their first year of medical school, while current/prior education status was not collected for learners in the public course runs. The study was conducted using anonymized data after the completion of the courses and awarding of any relevant certificates to learners and was determined not to be human subjects research by the Harvard Medical School Office of Human Research Administration.

Structure of the Courses

Each of the courses comprises a series of lessons based on specific topics. These lessons consist of a variety of different types of videos, including teaching videos involving writing and/or animations, clinical pieces involving doctors and patients, text, assessments, and interactive visualizations. All course materials were created using evidence-based learning practices. Specifically, all videos in the courses are designed to be short, with the majority under 7 min, and employed a variety of video types, both of which have been shown to increase student engagement [13]. Additionally, many of the course lessons include
real-world examples, including interviews with clinicians and patients, which can also enhance student learning [14]. Finally, all lessons include spaced repetition and interleaving of the subjects to enhance retention of the subject matter [15–18]. The lessons were released sequentially over the course period, with a final exam at the end of the course. The pre-course quiz was released with the first lesson at the outset of the course, while the post-course quiz was released with the final lesson as a review for the final exam.

Pre- and Post-Course Quizzes

For each course, the pre- and post-course quizzes were identical, and consisted of 15–20 multiple-choice questions based on the course material. Following the pre-course quiz, neither the question answers nor the learner's score was revealed, though learners could see the correct answers to the questions after taking the post-course quiz. Therefore, only individuals who took the post-course quiz after the pre-course quiz were included in the study. Each question was accompanied by the question “How confident are you that your answer is correct?” with a Likert scale response ranging from 1 (“Not at all confident”) to 5 (“Extremely confident”). Learners were not required to provide answers or self-confidence assessments for all questions in order to submit their pre- and post-course quizzes.

Calculation of the Confidence Score (C-Score)

In order to measure changes in learner confidence while accounting for whether or not that confidence was merited (aligned with their knowledge), we created a “confidence score” or “C-score” based on Gardner-Medwin [19]. The C-score is defined as:

$$C\text{-score} = \sum_{i} x_i \times \text{confidence}_i$$

where

$$x_i = \begin{cases} 
-1 & \text{if the individual answered question } i \text{ incorrectly} \\
0 & \text{if the individual did not answer question } i \\
1 & \text{if the individual answered question } i \text{ correctly}
\end{cases}$$

and

Table 1 The number of learners included in the study, separated by course and cohort type

| Course      | Cohort type                   | Total number of enrolled individuals | Number (percentage) of individuals who completed course | Number (percentage) of individuals who completed the course with pre- and post-course quiz data |
|-------------|-------------------------------|--------------------------------------|--------------------------------------------------------|----------------------------------------------------------------------------------|
| Biochemistry | US-based medical schools      | 412                                  | 283 (68.69%)                                          | 213 (51.70%)                                                                    |
|             | Non-US-based medical schools  | 380                                  | 322 (84.74%)                                          | 194 (51.05%)                                                                    |
|             | PCR                           | 1917                                 | 1288 (67.19%)                                         | 719 (37.51%)                                                                    |
|             | Total                         | 2709                                 | 1893 (69.88%)                                         | 1126 (41.57%)                                                                   |
| Genetics    | US-based medical schools      | 674                                  | 591 (87.69%)                                          | 351 (52.08%)                                                                    |
|             | Non-US-based medical schools  | 1417                                 | 1232 (86.94%)                                         | 476 (33.59%)                                                                    |
|             | PCR                           | 2231                                 | 1610 (72.16%)                                         | 974 (43.66%)                                                                    |
|             | Total                         | 4322                                 | 3433 (79.43%)                                         | 1801 (41.67%)                                                                   |
| Immunology  | US-based medical schools      | 1092                                 | 905 (82.88%)                                          | 608 (55.68%)                                                                    |
|             | Non-US-based medical schools  | 1835                                 | 1572 (85.67%)                                         | 751 (40.93%)                                                                    |
|             | PCR                           | 3646                                 | 2765 (75.84%)                                         | 1677 (46.00%)                                                                   |
|             | Total                         | 6573                                 | 5242 (79.75%)                                         | 3036 (46.19%)                                                                   |
| Pharmacology| US-based medical schools      | 441                                  | 438 (99.32%)                                          | 306 (69.39%)                                                                    |
|             | Non-US-based medical schools  | 779                                  | 740 (94.99%)                                          | 511 (65.60%)                                                                    |
|             | PCR                           | 1895                                 | 1482 (78.21%)                                         | 980 (51.72%)                                                                    |
|             | Total                         | 3115                                 | 2660 (85.39%)                                         | 1797 (57.69%)                                                                   |
| Physiology  | US-based medical schools      | 974                                  | 777 (79.77%)                                          | 450 (46.20%)                                                                    |
|             | Non-US-based medical schools  | 1048                                 | 977 (93.23%)                                          | 552 (52.67%)                                                                    |
|             | PCR                           | 2298                                 | 1643 (71.50%)                                         | 1028 (44.73%)                                                                   |
|             | Total                         | 4320                                 | 3397 (78.63%)                                         | 2030 (46.99%)                                                                   |
| Grand total |                               | 21,039                               | 16,625 (79.02%)                                       | 9790 (46.53%)                                                                   |
Statistical Analyses

Final exam scores were compared between learners with pre- and post-course quiz data to those without using a permutation test with 100,000 random permutations of the data per course. Learners were separated into quartiles based on their performance on the pre-course quiz. For individual learners, pre- vs post-course quiz scores, pre- vs post-course quiz confidence, and C-scores were compared using the Wilcoxon signed-rank test and effect sizes were calculated using Cohen’s $d$ [20]. Wilcoxon tests were performed using Scipy v1.5.3, Cohen’s $d$ was calculated using a Python script, and all graphs were produced using matplotlib v3.3.3.

Results

In total, 16,625 learners from 150 cohorts completed courses during the studied time period, of whom 9790 (58.90%) completed both the pre- and post-course quizzes. To determine whether the sample of learners who took the pre- and post-course quizzes was representative of all learners who completed the courses, the mean final exam scores were compared between completers who took the pre- and post-course quizzes for each course and those who did not using a permutation test. For all five courses, the mean final exam scores for the learners for whom pre- and post-course quiz data are available were significantly higher than the mean final exam scores for those who did not (Table 2). Although these results suggest differences worth looking at in future studies, the large number of learners completing pre- and post-course quizzes represent a wide variety of backgrounds and can provide insights into the learning behaviors of a diverse group of individuals.

For all courses, the median post-course quiz score was significantly greater than the median pre-course quiz score (Table 3). When learners were separated based on their pre-course quiz quartile, learners in each quartile showed a significant increase in post-course quiz score, indicating that the learner performance improved regardless of their starting knowledge (Figs. 1A and S1). For learners in the lower three quartiles of pre-course quiz performances, the courses had a large, positive effect on post-course quiz score both taken in aggregate (Table 4) and for all individual courses (Table S1). Those in the top quartile saw a medium increase when taken as a whole, while individual courses exhibited small to large increases (Tables 4 and S1).

For all courses, the median self-assessed learner confidence on the post-course quiz was significantly greater than on the pre-course quiz (Table 3). When learners were separated based on their pre-course quiz quartile, learners in each quartile showed a large increase in confidence, indicating that the learner confidence also improved regardless of their starting knowledge (Tables 4 and S1, Figs. 1B and S2).

### Table 2

| Course       | Mean exam score — learners without pre- and post-course data | Mean exam score — learners with pre- and post-course data |
|--------------|-------------------------------------------------------------|----------------------------------------------------------|
| Biochemistry | 63.64%                                                      | 70.41%*                                                  |
| Genetics     | 64.71%                                                      | 72.44%*                                                  |
| Immunology   | 81.15%                                                      | 84.95%*                                                  |
| Pharmacology | 77.74%                                                      | 83.77%*                                                  |
| Physiology   | 69.59%                                                      | 72.88%*                                                  |

*Represents a $p$-value < 0.00001 using a Wilcoxon signed-rank test

### Table 3

| Course       | Median percent correct | Median confidence | Median C-score |
|--------------|------------------------|-------------------|----------------|
|              | Pre-course Post-course| Pre-course Post-course | Pre-course Post-course |
| Biochemistry | 50.00% 75.00%*         | 2.71 3.95*        | 8 36*           |
| Genetics     | 35.00% 70.00%*         | 2.75 4.00*        | −3 27*          |
| Immunology   | 45.00% 80.00%*         | 2.13 3.94*        | 1 48*           |
| Pharmacology | 40.00% 85.00%*         | 2.35 4.15*        | −3 56*          |
| Physiology   | 46.70% 73.33%*         | 2.67 3.80*        | 3 23*           |

*The maximum C-score for biochemistry, genetics, immunology, and pharmacology was 100, while the maximum C-score for physiology was 75 due to a shorter quiz
*Represents a $p$-value < 0.00001 using a Wilcoxon signed-rank test
Similarly, for all courses, the median learner C-score on the post-course quiz was significantly greater than on the pre-course quiz (Table 3). The C-score is a measure that combines learner confidence and correctness by increasing when they answer a question correctly and decreasing when they answer incorrectly in proportion to the learner’s self-assigned confidence. Therefore, a learner with a high level of misplaced confidence, as indicated by having high confidence on questions they answer incorrectly, will get a negative score, whereas learners who are confident in only correct answers will have a high positive score. Learners with scores near zero lacked enough correct answers or confidence in their answers to obtain a highly positive score. Learners in the lowest quartile of all courses, and the second quartile for genetics, immunology, and pharmacology, had an average C-score of less than 0 on the pre-course quiz. In the post-course quiz, these C-scores had all become positive, and learners in each of the quartiles exhibited a significant increase in average C-score (Figs. 1C and S3). As was seen with post-course quiz scores, learners in the lower three quartiles of pre-course quiz performances saw a large, positive effect on C-score both taken in aggregate (Table 4) and for all individual courses (Table S1). Those in the top quartile again experienced a medium increase when taken as a whole, while individual courses exhibited small to large increases, depending on the course (Tables 4 and S1).

These results were true for learners from all three types of cohorts: US-based medical schools, non-US-based medical schools, and public course runs (Fig. S4). In all cases, median score, median confidence, and median C-score increased significantly between the pre-course quiz and the post-course quiz.

**Discussion**

This study across a large number of learners demonstrates that online courses developed using evidenced-based learning principles are reliably able to significantly increase learners’ knowledge levels in topics related to the foundational medical sciences that form a critical knowledge base for medical education. In total, 79.02% of learners who enrolled in these courses completed the courses (Table 1) which is much greater than the baseline that has been observed in many MOOCs [12]. Learners who completed online courses covering the fundamentals of biochemistry, genetics, immunology, pharmacology, and physiology showed increased knowledge in the subject matter (Figs. 1A, S1, and S4A–E), greater confidence in their answers (Figs. 1B, S2, and S4F–J), and a better association of high confidence with providing the correct answer to a given question (Figs. 1C, S3, and S4K–O). This increase in both knowledge and confidence indicates that well-designed online courses can provide effective learning in these subjects and reduce the differences in knowledge and confidence between groups of students.
The significant increase in learning was consistent across all groups of individuals, including those from US-based medical schools, non-US-based medical schools, and public course runs. This indicates that these courses are able to provide learning to many different types of individuals with different backgrounds and preparation. Information on the educational status of those enrolled in the public course runs was not collected, but follow-up surveys and interviews with a subset of learners from all courses indicate that only a minority of learners in any courses have received specific education on these topics beyond the equivalent of an undergraduate education. Although those attending medical schools of any type may be assumed to have some similarities in terms of baseline knowledge, as they have been accepted into a health sciences higher education program, the online courses discussed here are generally taken prior to the start of medical school or during the first year, and those enrolled in these courses have not yet taken the corresponding topics in their school’s existing curriculum. Therefore, they may still have significant differences in their educational backgrounds and level of preparedness depending on their prior science education. Learners enrolled in public course runs may exhibit even greater variation, as they may be at any stage of their education from pre-college to many years after graduating, but also trend not to have previously participated in educational experiences related to the online courses that are the subject of this study. The fact that there are large improvements in all of these groups, as well as in subgroups stratified by pre-course quiz quartile, indicates that these courses are effective at teaching individuals regardless of their background. This indicates that these courses can help to reduce some of the differences in preparation prior to medical school or early in medical school studies, creating cohorts with greater readiness for successful entry in medical education.

The increase in self-assessed confidence in learners’ answers shows that these improvements in test performance were accompanied by increased confidence in their own abilities. Further, the significant increase in learner C-scores also indicates that learners are not only becoming more confident in their knowledge, but they are also increasing their ability to correctly determine when they should be confident. On the pre-course quiz, the median C-score was close to or below zero for many learners, especially those in the lowest quartiles of pre-course quiz performance, indicating that they did not frequently answer questions both correctly and with high confidence. On the post-course quiz, all quartiles of learners in all courses had greatly increased, positive C-scores, indicating that the increases in self-confidence were accompanied by more frequently answering the accompanying questions correctly. This indicates a strong increase in the learners’ ability to assess their own knowledge, which has been identified as an important skill and a target for improvement in higher education [4, 5].

While these courses led to improved performance by individuals in all quartiles of pre-course quiz performance, those in the lowest quartile generally experienced the largest gains. While this may be partially explained by the ceiling effect limiting the amount of improvement that can be observed in individuals in the highest quartile, it indicates that poor performers are being brought closer to the level of their peers. The median post-course quiz scores of individuals from all quartiles of pre-course quiz scores were as high or higher than the median pre-course score of the top quartiles of pre-course quiz performances. This indicates that the knowledge gap among the learners has significantly decreased. Together, these improvements suggest that the individuals who took these courses were more similar in their level of preparedness after the courses than they were before. In this way, online courses such as these could be used to ensure that all learners in a large cohort are prepared with similar baseline knowledge prior to beginning a further course of study such as medical school, which may improve their long-term performance. Decreasing the real or perceived differences in preparation between different groups of students may encourage additional students to apply to and remain in medical school, helping to increase medical school diversity.

These courses were all created with considerable effort applied to the instructional design and underlying learning science and the results may not be generalizable to all online courses. Different methods of construction of online and blended courses can greatly affect the outcomes of those courses [21–23]. The courses included in this study were purpose-built for online learning using the best practices according to our current knowledge, such as using short videos and relevant clinical examples, with authentic, applied, real-world examples, spaced repetition of concepts, and interleaving [13–18]. Therefore, it is important to consider curricular design as a potential confounding factor when comparing disparate online courses.

Additionally, not all individuals who completed the course completed the pre- and post-course quizzes for each course and those that did had a higher average final exam score than those who did not complete one or both quizzes (Table 2). This indicates that the group included in this study may not be representative of all individuals who completed the courses. However, the fact that individuals from all cohorts and quartiles of pre-course quiz performance showed increases in learning and confidence indicates that these courses are likely to improve the performance of all learners, regardless of their prior preparation or final exam performance.
Future Directions

While this research demonstrates that online courses can increase learner knowledge in subject areas related to the foundational biomedical sciences, several questions remain. Future studies should be conducted to determine the real-world effects of taking these or similar online courses in the foundational biomedical sciences. For instance, researchers should ascertain whether or not the increased preparation and confidence imparted by taking these courses leads to increased medical school application rates across diverse populations and whether or not these gains lead to better outcomes during medical school. Further research should investigate the best practices for designing and developing online courses in order to maximize learning. This may include production and delivery issues such as determining optimal length of videos and the frequency of testing, content-based issues such as what material to cover and how to organize the courses, and learner motivation issues such as how to encourage individuals to complete materials in a timely manner rather than rushing through [21, 23]. Additional technological advances, such as machine scoring of learners’ written submissions, may also increase the tools available to create online courses, and it will be important to assess the utility of these tools as they arise. Investigation into the behaviors of high-performing learners will also be helpful in determining the best way to design and administer online courses. Finally, increasing the number of individuals from whom data is collected, as well as gathering information from a larger number of US-based and non-US-based medical schools, will help us to understand how best to employ online courses in different circumstances and maximize their effectiveness for each subgroup.

Conclusion

Online learning is becoming more prevalent in many fields, including the biomedical sciences. This study has shown that online courses in the foundational biomedical sciences can lead to significant increases in learner knowledge as well as increases in learner self-confidence. The results indicate that online courses such as these are a useful tool in providing the information necessary for individuals to succeed in medical school and beyond. Online courses may provide access to these materials to individuals from many backgrounds, and can serve as a method of helping to bring all learners up to a similar baseline, reducing the differences in preparation due to different learner backgrounds. More research into the best practices and behaviors of online learning is needed, but this study shows that online courses can be a useful tool in biomedical education.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s40670-022-01660-4.

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Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by AP, MB, and MP. The first draft of the manuscript was written by AP, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declarations

Ethical Approval

This study was determined not to be human subjects research by the Harvard Medical School Office of Human Research Administration.

Conflict of Interest

The authors declare no competing interests.

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