JOURNAL OF CHEMICAL EDUCATION
Commentary
pubs.acs.org/jchemeduc

Pencil–Paper Learning Should Be Combined with Online Homework Software

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ABSTRACT: For the past eight years, we have used online homework software as a pedagogical tool for undergraduate students (almost all are second-year students) learning organic chemistry. Being strong proponents of homework, we were surprised to find that about half of the students who complete 90% or more of the online homework assignments received less than 50% of the available points on examinations, even though comparable problems were given. Students who combined traditional pencil–paper problem solving with the online software performed better than students who solely used the online homework package. Our findings contribute to the ongoing debate between pencil–paper and computer learning with the recommendation that they should be combined to provide students with the ultimate learning tool.

KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, First-Year Undergraduate/General, Communication/Writing, Computer-Based Learning, Hands-On Learning/Manipulatives, Misconceptions/Discrepant Events*

■ INTRODUCTION

Organic chemistry is and always has been a difficult course to master for most students. A student's success in a chemistry course is strongly correlated to on-task studying of the material through solving homework problems.[1] With large undergraduate class sizes, such as the ones at the University of Cincinnati, hand grading of homework problems and providing students with valuable feed-back is impractical. Online homework overcomes most of these obstacles. The computer software acts as the instructor, providing the correct answers, guidance, and tutorials.[2] Furthermore, the software is a diagnostic tool for the instructor to monitor individual and overall performance. Students appreciate the immediate feedback provided by the software, which reinforces the topic being taught and fosters a more positive study attitude.[3,4] However, it has been found that most students need to receive points toward their final scores before they will complete online homework problems.[3] Over the past decade, many studies have shown a positive relationship between online homework and a student's total points/course grade.[1−6] In general, the total points/course grade for the students who perform well on the online homework is higher than for students who do not complete online homework assignments. In addition, those students who complete online homework on average do better on examinations in comparison to those students who do only written homework.[7]

For our organic courses, taught by four professors over the past eight years, we observed the same positive relationship between online homework and examination performance as determined by the examination averages. However, looking more deeply into these data, we unexpectedly discovered that excellent performance on online homework is not a predictor of examination performance. Specifically, we find that half of the students who earn the majority of points on the online homework are significantly below average on the examinations. In addition, we find that students who combined traditional pencil–paper problem solving with the online software performed better than students who solely use the online homework package.

■ METHOD—ONLINE HOMEWORK SETUP

For those only familiar with online homework packages for a general chemistry course, please be aware that online homework for organic chemistry is somewhat different. Similar to general chemistry problems, the organic package contains multiple-choice questions, but the possible algorithmic variations of a single problem are much more limited. In addition, unlike the general chemistry problems, online homework for organic chemistry contains a large number of problems that require using a drawing program to show the product of a reaction or to show the arrows for a mechanism.

The organic professors at the University of Cincinnati have used Connect or OWL as homework packages. These programs were chosen, in part, because they are integrated with course textbooks and contain a subset of the back of the chapter problems. Connect and OWL are both interactive homework packages providing students with feedback, guidance, and tutorials. The problems are parametrized such that if a problem is repeated, it is a new problem that investigates the same concept with different values or molecules. For Connect, we also provided LearnSmart, which is an interactive tool that adaptively assesses a student's knowledge and confidence level of organic topics. Both Connect[7] and OWL[8] have been shown to improve student performances in organic chemistry courses.

Regardless of which package was used by us, online homework accounted for about 15% of the total points for the course. For the online homework, we assigned 15 problem sets with questions based on the material discussed in each hour and a half class period. To earn all the possible points, a student needs to solve around 160 problems per semester. The remaining points in the course were generally divided into quizzes worth between 0% and about 15%, two or three

DOI: 10.1021/ed500594g
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 1. Examination Average versus Online Homework Data

Parameter	Connect (N = 1143)	OWL (N = 2280)	ACS Examination (Connect Homework) (N = 246)	ACS Examination (OWL Homework) (N = 219)
Exam average[a] for all students, %	48	50	46	52
Exam average[a] for students who earned 90% or more of the online homework points, %	55	56	52	59
Exam average[a] for students who earned 50% or fewer of the online homework points, %	31	33	40	42
Exam median for all students, %	49	50	44	50
Exam median for students who earned 90% or more of the online homework points, %	56	55	49	61
Exam median for students who earned 50% or fewer of the online homework points, %	29	33	36	38

[a]Standard deviation for each of the averages is approximately 17%.

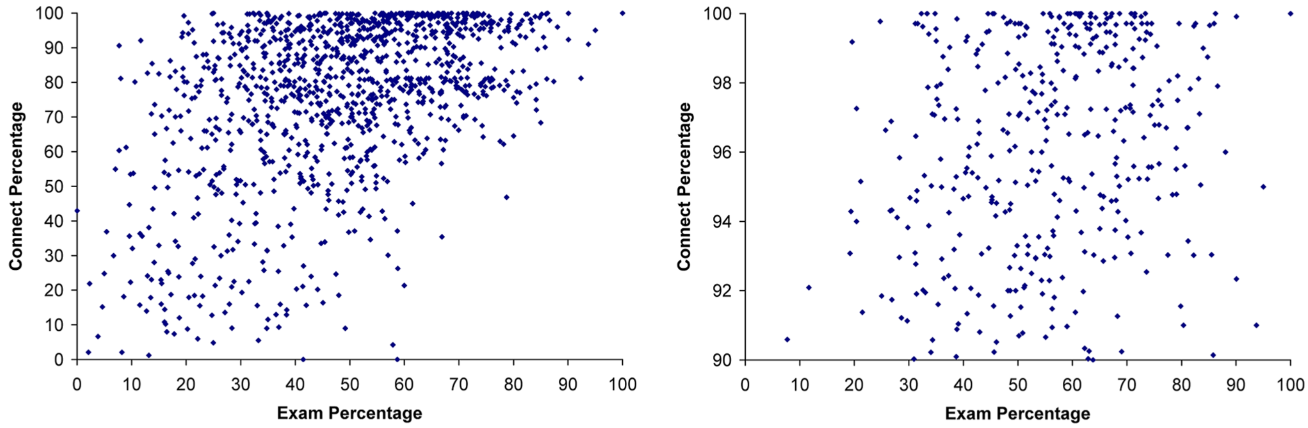

Figure 1. Connect percentage versus examination percentage. The left graph is all the students, and the right graph is those students who earned 90% or more of the online homework points. The correlation coefficient for the left graph is 0.450 and for the right graph is 0.205.

examinations worth a total of 40−55%, and a final examination worth about 30% of the total points. The examinations use pencil and paper and do not contain multiple-choice questions. A full range of typical organic chemistry questions are asked including topics such as nomenclature, physical and chemical properties of molecules, stereochemistry, products from reactions, synthesis, and mechanisms.

The authors believe that online homework is a very promising pedagogical tool. Because we are strong proponents of homework problems as an instructional tool for organic chemistry, students are given a large number of attempts and are given feedback after each attempt. We realize that this method of administering the online homework enables a student to acquire all the homework points through guessing. On the other hand, we felt that limiting the number of attempts would be more stressful by treating homework as an examination rather than a learning experience. Our approach is supported by a recent study that found students were most appreciative of the immediate feedback, the opportunity of multiple attempts, and the ease of the Connect program when solving online homework.[7] In two of our large classes (approximately 350 students), we discovered that most students completed each problem set using only two to three attempts (the average is 2.2 ± 0.4 attempts per problem set). Furthermore, we found that most students spent a significant amount of time working homework problems, apparently in an attempt to master organic chemistry.

In this study, we use Pearson correlation coefficients to measure the linear correlation between the percentage of examination points versus the percentage of online homework completed. A statistical analysis was performed on students' use of the Connect program (averaged time spent actively working on the problems and the averaged number of attempts) to determine if there was a significant difference in the methods used by students to complete the online homework assignments.

■ RESULTS

For the past two academic years, we used Connect. For our courses, a total of 1143 students completed organic chemistry. As can be seen in Table 1, we compare the percentages of online homework completed to examination scores. We do not compare percentages of online homework completed to the total points because the total points include the online homework, and thus, bias the results. We also exclude quiz scores since some courses did not give quizzes. As the data show, those students who earn 90% or more of the points for the online homework did better on the examinations than the class as a whole (56% vs 48% of total examination points, Table 1). In contrast, students who complete less than 50% of the online homework generally do more poorly (31% vs 48% of total examination points, Table 1). The large standard deviation of approximately 17% makes the difference in these numbers less relevant. Because of this rather large standard deviation for the averages, we also looked at the median value and obtained similar percentages. Thus, our findings are consistent with previous literature studies; those students who do well on the online homework, on average, do better on the examinations than the class as a whole.

DOI: 10.1021/ed500594g
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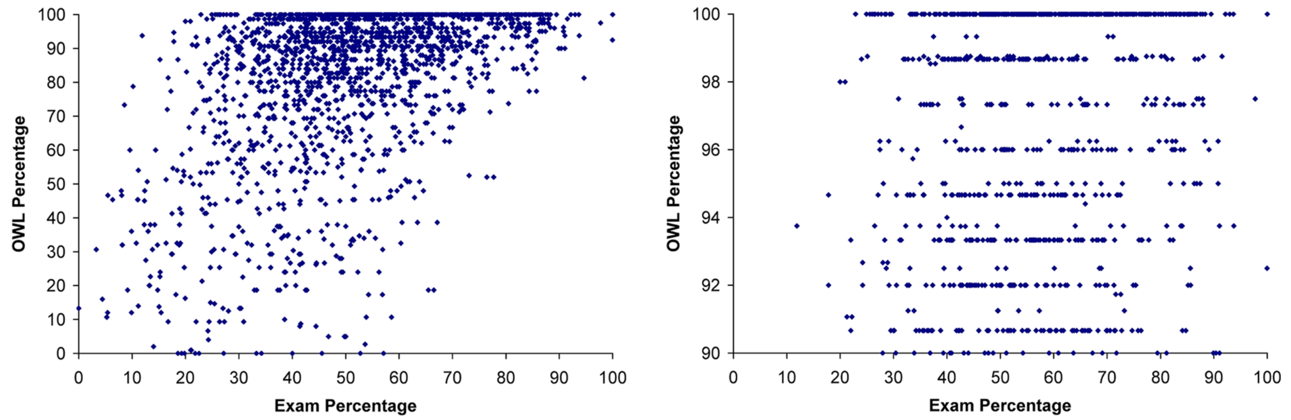

Figure 2. OWL percentage versus examination percentage. The left graph is all the students, and the right graph is those students who earned 90% or more of the online homework points. The correlation coefficient for the left graph is 0.443 and for the right graph is 0.115.

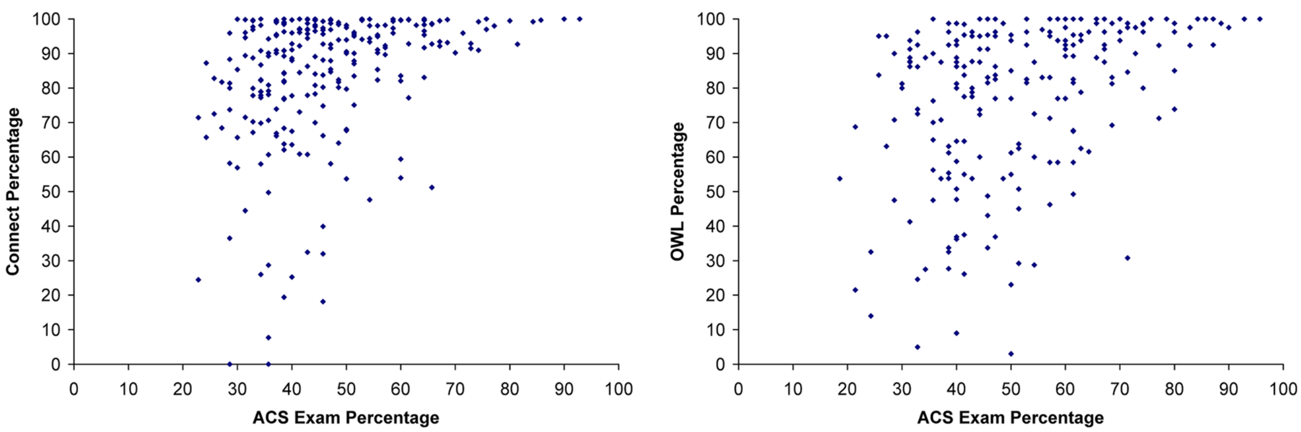

Figure 3. Online homework percentage versus ACS standardized exam percentage. The left graph is for Connect, and the right-hand graph is for OWL. The correlation coefficient for the left graph is 0.337 and for the right graph is 0.402.

When the examination percentage versus the online homework percentage is plotted (Figure 1), we find it is true that students who perform poorly on the online homework also perform poorly on the examinations. However, we find no relationship between online homework points and examination scores for those students who earn most of the online homework points (Figure 1, right graph). The Pearson correlation coefficient drops from 0.405 when comparing all students to 0.205 when comparing only students who solved at least 90% of the online problems. Put another way, if a student does poorly on the online homework, he or she will likely perform poorly on the examinations. However, if a student does really well on the online homework, one cannot predict how well that student will perform on the examinations.

Next, we wanted to determine whether this was a general trend or something specific to the Connect package we are currently using. In previous years, we used the OWL homework software. Because we used it for a longer period of time, we have more data. As can be seen in Table 1, the general trend is the same as seen with Connect. The higher the percentage of points earned for the online homework, the higher the examination average or median; however, the same high standard deviation is obtained. Plotting these data, as shown in Figure 2, shows that students who perform poorly on the online homework perform poorly on the examinations, but once again, there is no correlation between completing 90% of the OWL homework and performing well on the examinations.

One could readily argue that the lack of correlation between online homework performance and examination performance is due to the fact that the problems given on the examinations are substantially different than the ones given online. We believe this is not true. As discussed previously, the problems given on the examinations are standard organic chemistry questions, and most of the examination problems are very similar to the homework problems. As an aid to the students to help them study, they are told at the beginning of each course that examination problems are very similar to the online homework problems. Furthermore, the scores reported were obtained from multiple classes taught by educators with different teaching styles.

To further explore the possibility that there is a disconnection between our examination questions and the online questions, we compared the online homework scores with the percentage of questions answered correctly on the ACS standardized examination (Table 1 and Figure 3). The same trend as discussed earlier was found with these standardized examinations—there is no relationship between doing well on the online homework, using either Connect or OWL, and how a student will perform on the ACS examination. (Because not all classes gave the ACS examination, we have fewer data points.)

DOI: 10.1021/ed500594g
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■ DISCUSSION

Because the graphs and the correlation coefficients are so similar, to expedite the discussion of the data, in Figure 4, we have combined the Connect (Figure 1) and OWL (Figure 2) data and have arbitrarily divided the graph into four quadrants of equal size. The students in Quadrant 2 (Q2) are generally well motivated, well prepared, and most likely would excel in organic chemistry independently of the style of homework. Notice that there are virtually no students in Quadrant 4 (Q4), namely, those students who do poorly on the online homework, but do well on the examinations.

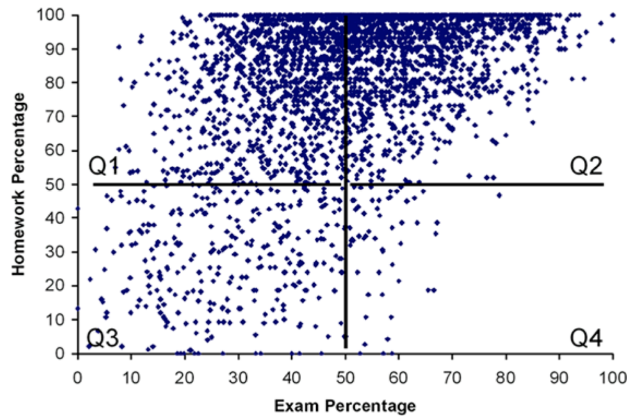

Figure 4. Homework percentage versus examination percentage. The data shown in Figure 1 and in Figure 2 have been combined, and the graph has been divided into four quadrants of equal size.

The students in Quadrant 3 (Q3) are the "nonparticipants". They do not complete the homework assignments and apparently do not study for examinations. This group is the main reason why the examination average or median for those who do online homework is higher than the examination average or median for the class as a whole.

The final group of students lies in Quadrant 1 (Q1). They score well on the homework assignments but perform poorly on the examinations. As seen with the entire population of students, there is no correlation between percentage of examination scores and percentage of online homework completed (Pearson correlation coefficient = 0.224). These students, who comprise approximately 40% of the class, would benefit the most from a well-crafted homework system. Most educators likely would agree that teaching students on a one-on-one basis is ideal. Current online homework programs provide this service conveniently because students can work a problem multiple times with constant feedback. So why are there so many students in Q1?

Because of the nature of the material in organic chemistry, the algorithmic variations for a problem are much more limited than for general chemistry problems. Thus, an unmotivated student may just randomly click responses until the correct answer is obtained. If one considers that the solution for many problems requires using a template to draw structures or to provide mechanistic arrows, the likelihood that students randomly provide correct answers is diminished. Another possibility, of course, is that a classmate simply provides the answers. In other words, these students are apathetic; they do not care about learning the material, only in obtaining the points.

We can test for student apathy because the Connect program provides the number of attempts and the total time actively working on each homework assignment. A student would only have to spend a small amount of time online to randomly click responses, randomly draw structures, or input correct answers obtained from a classmate. If student apathy is the key, then we should observe a correlation between students' attempts or time spent on online homework versus examination percentage.

We plotted the total amount of time a student spent actively engaged on homework problems versus the examination percentage for students who earned 90% or more of the online homework points for one large class (134 students out of a total of 240 students, Figure 5). There is no correlation.

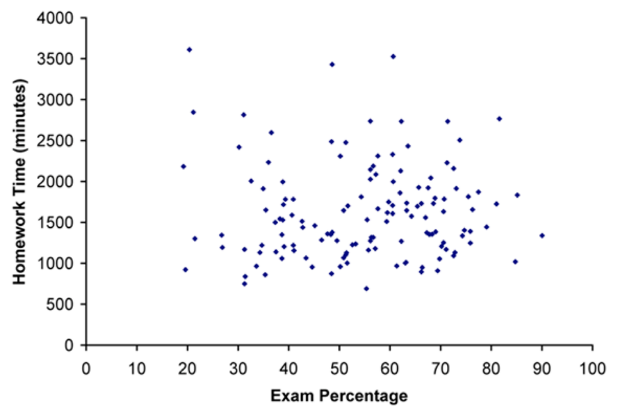

Figure 5. Time spent on online homework versus examination average. The data were taken from a single large organic chemistry class. The correlation coefficient for the graph is 0.000.

Statistically, the same amount of time was spent on homework for students who received greater than 70% of the examination points as for students who received less than 40% of the examination points (1640 ± 500 min and 1640 ± 700 min, respectively). Similarly, as mentioned earlier, the average number of attempts per problem set is 2.2 ± 0.4 regardless of examination scores.

We now turn to the possibility that there could be an inherent problem with current online homework software that may hinder learning organic chemistry, and possibly material in other courses as well. There appears to be a slowly evolving paradigm shift in learning at all levels from pencil and paper to computers. Ever since computers have become a standard resource in the classroom, there have been many interesting studies exploring the benefits and costs of using computer software versus traditional pencil and paper in learning.[9−14]

One possible supposition is that students who solve the majority of the homework problems using the online software, but performed poorly on examinations, did not benefit from drawing organic molecules and reaction mechanisms with a pencil. Support for this hypothesis comes from a report that shows learning by handwriting facilitated subjects' memorization of graphic forms as compared to using a computer only.[9−11] Similarly, these authors[9]

> *[C]ompared children's learning of a series of abstract graphic forms depending on whether they simply looked at the forms or looked at them as well as traced the forms with their index finger. The tracing movements seemed to improve the children's memorization of the graphic items.*

This type of "motor-memory" is also important in adult learning, including learning new symbols.[12] A recent fMRI

DOI: 10.1021/ed500594g
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(functional magnetic resonance imagining) study on adults[13] demonstrated that processing letters produced by writing versus by typing occurs in different parts of the brain. Writing letters via pencil−paper produced greater activity in areas that are involved in imagery, execution, and the observation of actions. Using pencil−paper has been recently found beneficial for taking class notes as well. Students who type their class notes do not retain knowledge as well as students who handwrite notes because of a shallower processing of the information.[14] Thus, motor-memory is obtained from handwriting or tracing but not from typing. It follows from these studies that students benefit from drawing new shapes, such as molecules and reaction mechanisms, with a pencil in comparison to the palette used in current software.

In contrast, a recent study[7] showed that for organic chemistry, students who used online homework had a higher percentile score than those who used only pencil−paper for homework. The author did not discuss if the students who used only pencil−paper for homework had a solutions manual as a guide. Furthermore, students who used online homework may or may not have used pencil−paper to solve the problems prior to putting the answers online.

To investigate the possibility that handwriting the answer to a problem is beneficial for examination performance, we asked students who used Connect if (a) they used only the computer software to solve problems, or (b) they wrote out the answer with pencil−paper first and then transferred the answer to the online program. Out of the 206 respondents, 128 (62%) stated they first used pencil−paper to solve any online homework problem (population of students who use pencil and paper with the online homework = $P_{\text{p−p/ol}}$), whereas the remaining 78 (38%) used solely the online homework package (population of students who only used the online package = P_{ol}). Because the students answered just yes or no to our question, we do not know how often paper and pencil were used to solve a problem prior to putting the answer online. The mean examination percentage for $P_{\text{p−p/ol}}$ is 57 (standard deviation = 18) and for P_{ol} is 51 (standard deviation = 20). The t-value (148 degrees of freedom) is 2.17 (t_{crit} = 1.65), and the p-value = 0.0157, which indicates a greater than 98% confidence level that the difference between the means is statistically significant. Similar results are obtained when comparing the two populations of students against the performance on the ACS examination. Only a subset of these student populations took the ACS examination ($P_{\text{p−p/ol}}$ = 53 students, and P_{ol} = 32 students). The mean examination percentage for $P_{\text{p−p/ol}}$ is 50 (standard deviation = 15) and for P_{ol} is 43 (standard deviation = 16). The t-value (55 degrees of freedom) is 1.96 (t_{crit} = 1.67), and the p-value = 0.0273, which indicates a greater than 97% confidence level that the difference between the means is statistically significant.

Thus, students who initially used pencil−paper to solve at least some of the organic problems performed better on the examinations than students who used only the computer to solve problems. Placing these results into our quadrant system shows that about one-third of the students who first handwrote some of their answers ($P_{\text{p−p/ol}}$) are in Q1, whereas over half of the students who only used the computer (P_{ol}) are in Q1. Our goal of getting students into Q2 is better accomplished when students combine pencil−paper with their online homework package (68% vs 45% of the students received greater than 50% of the examination points, Figure 6).

A statistical analysis was performed using the Connect software diagnostics to see if these two groups of students could be differentiated on the basis of their use of the program or if they were just given the answers by friends, instead of whether or not they used pencil and paper. Both groups of students solved the same percentage of the homework problems ($P_{\text{p−p/ol}}$ solved 84 ± 20%, and P_{ol} solved 84 ± 18% of the homework problems). On average, students who used pencil−paper with the online homework ($P_{\text{p−p/ol}}$) spent 1700 ± 600 min to complete the homework problems, whereas students who used only the online software (P_{ol}) on average spent 1800 ± 900 min to complete the homework problems. The average number of attempts to complete each of the 15 weekly assignments was similar as well. For $P_{\text{p−p/ol}}$, four assignments averaged a single attempt, seven assignments averaged two attempts, three assignments averaged three attempts, and one assignment averaged greater than three attempts. For P_{ol}, four assignments averaged a single attempt, seven assignments averaged two attempts, two assignments averaged three attempts, and two assignments averaged greater than three attempts. Because the two groups are statistically very similar, it appears that both populations of students spent a similar amount of time on homework, took advantage of the online homework guidance features, and were not just given the answers by friends. Thus, our results suggest that initially solving homework problems with pencil−paper appears to be an important method for learning.

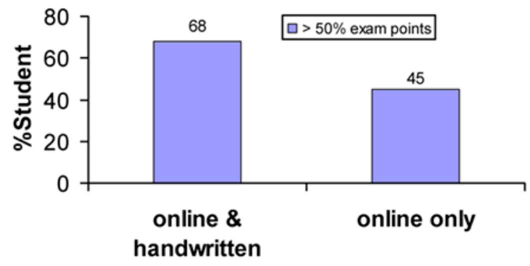

Figure 6. Online and handwriting versus online only. Students who initially handwrote solutions to some of the online problems performed better on examinations than students who solely used the online homework package.

On the basis of these findings (Figure 6), we now recommend that our students use pencil and paper to do their online homework, and thus to study for their examinations. However, because students are naturally reluctant to complete homework twice, a better solution would be to develop further online homework software that uses a stylus and onscreen writing to enable students to hand draw molecular structures and mechanisms. Such software has been demonstrated but not applied to online homework software.[15,16] The combination of pencil−paper with computer learning would likely benefit students who study other disciplines as well.

■ CONCLUSION

Online homework has succeeded in getting students of all abilities to complete homework problems. We find that students spend many minutes on each problem and take advantage of the hints and the repeated attempts. What needs to be improved are the examination scores for about half of the students who have earned 90% or more of the online homework points. In this commentary, we introduce the possibility that the lack of handwriting may account for part of the poor examination performance. Handwriting causes motor-memory, which appears to be important for organic chemistry

DOI: 10.1021/ed500594g
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students who are drawing complex molecular compounds. The authors encourage more studies on the ramifications of learning online versus the traditional use of pencil and paper. More specifically, studies on the ramifications of using a mouse and a keyboard versus using some type of a writing tool will be helpful. These studies would not only benefit students who take organic chemistry, but also all students who learn online.

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The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank our colleagues Deborah Lieberman and James Mack for allowing us to incorporate their student performances into our data. We also thank the anonymous reviewers of this paper for many very helpful suggestions.

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