Teaching medical students basic neurotransmitter pharmacology using primary research resources

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Halliday AC, Devonshire IM, Greenfield SA, Dommett EJ. Teaching medical students basic neurotransmitter pharmacology using primary research resources. Adv Physiol Educ 34: 205–212, 2010; doi:10.1152/advan.00005.2010.—Teaching pharmacology to medical students has long been seen as a challenge, and one to which a number of innovative approaches have been taken. In this article, we describe and evaluate the use of primary research articles in teaching second-year medical students both in terms of the information learned and the use of the papers themselves. We designed a seminar where small groups of students worked on different neurotransmitters before contributing information to a plenary session. Student feedback suggested that when the information was largely novel, students learned considerably more. Crucially, this improvement in knowledge was seen even when they had not directly studied a particular transmitter in their work groups, suggesting a shared learning experience. Moreover, the majority of students reported that using primary research papers was easy and useful, with over half stating that they would use them in future study.

How We Teach

undergraduate teaching, irrespective of discipline, must teach both subject-specific knowledge and transferable skills. The most cost-effective way of teaching large numbers of students is still to use lecture-based teaching despite the recommendation over a decade ago that teaching in small groups is more effective (1a). The teaching of medical students in particular has long been recognized as especially difficult, with Jonas (3) stating one reason being “the need to teach independent learning and problem-solving skills...while contending with the lack of clinical relevance in basic science.” Furthermore, Walley (13) suggested that traditional undergraduate teaching in pharmacology does not train medical students adequately.

Teaching pharmacology to medical students is unique in that it requires the integration of basic and applied knowledge to form the basis of a physician understanding of the mechanisms by which prescribed medications work (2). Such has been the interest in teaching pharmacology to this particular student population that a number of innovative methods have been trialled, including the use of popular culture video clips (12), research projects (10), and extended essays (6). In addition to these, the more conventional approach of using classic research papers in teaching is also often used for a range of topics (5, 8). The use of such articles effectively provides students with both the fundamental information and experience of working with research articles in a structured manner. However, while the use of classic papers is increasing, it is often limited to illustrating established findings; the currently published literature suggests it is most commonly employed in teaching basic science rather than clinical relevance.

The manner in which teaching is led has also been investigated with regard to medical students. Recent findings have shown that second-year medical students working in self-selected groups (i.e., team-based learning) report higher satisfaction and better performance than those working individually (14) when studying pharmacology. This is in line with other health courses and suggests a positive effect of group learning in this population of students (4, 7, 11).

At the University of Oxford, the Bachelor of Medicine degree is taught over 3 yr using lectures, seminars, tutorials, practical classes, and visits to general practices and hospitals. Whereas the lectures are typical in that information is delivered in a didactic form to a large group of students, the seminars are used to reinforce and discuss in more detail information that has been covered in lectures. The smaller group size of a seminar encourages discussion of a topic, and such sessions are generally run by specialists in the field, not necessarily university lecturers. Additionally, due to the college system within the university, students often have small-group tutorials (1–4 students) that normally answer essay questions based on the material covered in lectures; however, the subject matter covered in tutorials is largely determined by the students themselves. All practical classes, lectures, and seminars are compulsory and are organized by the Medical Sciences Teaching Centre, which runs the degree course. Tutorials are organized and taught within colleges by college tutors and lecturers in a more informal manner.

In the first year of their degree, students will study 17 different topic areas, which can be broadly grouped into anatomy, cellular and molecular biology, physiological systems, embryology, pharmacology, biochemistry, endocrinology, medical sociology, and medical statistics. Students are introduced to synaptic pharmacology during the first-year syllabus within the “Excitable Cells: Neural Communication” topic, where tissues and the basic divisions of the peripheral and autonomic nervous systems, nerve conduction, synaptic transmission, and muscle innervation are taught. Specifically, the section on divisions of the peripheral nervous system includes the role of ACh and norepinephrine in the autonomic nervous system, whereas the section on synaptic transmission covers the role of ACh in neuromuscular junctions and provides an overview of the variety of transmitters, excitatory and inhibitory postsynaptic potentials, and synaptic integration. The synaptic transmission section also includes inhibitory postsynaptic potentials and autonomic synapses, again with a focus on cholinergic and noradrenergic synapses.
The second-year syllabus is split into four major topics, including “Systems of the Body: Integrative Aspects,” “The Nervous System,” “Principles of Pathology,” and “Psychology for Medicine.” Of relevance to our present work is “The Nervous System” topic, which includes the coverage of all major neurotransmitters, including their synthesis, actions, receptors, and breakdown/removal. It is taught over 41 lectures, 9 long practical classes (lasting up to 3 h), 11 short practical classes (60–90 min), 11 demonstrations, 1 general practice visit, and 1 seminar. As part of this topic, “Synaptic Transmission” is taught in the first term in two lectures to the whole year group, and one seminar entitled “Synaptic Pharmacology” is given in groups of 15–20 students. Therefore, the seminar follows the only two lectures given on this broad topic and, as such, is an important opportunity to provide more detailed and in-depth information to the lecture material.

Seminars also provide a valuable opportunity for groups of students to interact and engage in active learning. Moreover, as the material has been covered in a lecture, and therefore is not entirely new, the seminars represent an excellent opportunity to develop additional skills to subject-specific knowledge. Here, we describe a single Synaptic Pharmacology seminar given to students in the first term of the second year of their Bachelor of Medicine degree, which, in addition to teaching the material, was also aimed to encourage the reading of original scientific literature to obtain both basic and clinical knowledge.

**Materials and Methods**

Students within the second year of their medical degree were split alphabetically into 8 groups of <20 students each, although the names of students were at no point divulged to the tutors running the seminars. The Synaptic Pharmacology seminar outlined here was held on four occasions in an identical fashion to four different groups. This accounted for half of the total (~160) students admitted to the degree each year; the remaining students participated in the four other seminars, which were carried out by different members of staff and not included in this study.

Students were given suggested reading material for the second-year Nervous System course, which incorporated this seminar, including *Neuroscience: Exploring the Brain* (1), *Principles of Neural Science* (3a), and *Neuroanatomy Text and Atlas* (5a). Students had access to the syllabus, which stated which parts of the course were covered by which lectures and seminars, and were expected to carry out their own preparation using these textbooks. No specific preparation was set for this seminar, although the students had previously had the two Synaptic Transmission lectures given to the entire second-year group in the immediately preceding weeks. We expected the students to have a previous understanding of norepinephrine and ACh signaling mechanisms, action potentials, and the mechanism of neurotransmitter release from the first-year course in addition to a broad overview of the synaptic transmission material presented in the second-year lectures.

The area of the syllabus covered by synaptic pharmacology, taught during the seminar outlined here, included chemical, excitatory, inhibitory, monoamine and cholinergic transmission within the central nervous system, and the regulation of receptors. Chemical messengers, fast and slow transmission, pre- and postsynaptic effects, concepts of neuromodulation, and volume transmission were discussed. The basis of neurotransmitter synthesis, release, degradation, and types of receptor were covered using glutamate, GABA, ACh, norepinephrine, dopamine, and serotonin as specific examples. Implications of up- and downregulation of receptor numbers and receptor desensitization after chronic stimulation or blockade were also covered. Drugs that inhibit neurotransmitter breakdown or mimic actions were discussed in relation to neuronal disorders, e.g., Alzheimer’s disease and depression.

The learning outcomes for this seminar can be separated into the following three main areas of knowledge and understanding (KU), key skills (KS), and cognitive skills (CS):

- **KU1**: understand the main processes involved in the production and removal/breakdown of all major transmitters and the effects of manipulating these processes.
- **KU2**: be able to name the major neurotransmitter pathways or brain regions.
- **KU3**: recognize that each transmitter may work at a number of receptors and that the exact effect on the postsynaptic neuron is determined by both the transmitter and the receptor.
- **KU4**: recognize the possible points of clinical intervention in these processes.
- **KU5**: recognize the variety of clinical relevance of the major neurotransmitter systems.
- **KS1**: be able to read and understand a variety of primary research resources.
- **KS2**: work as a group to provide an overview of the scientific research.
- **CS1**: be able to present information in a suitable manner during plenary discussions.

The 2-h seminar consisted of three activities; ~40 min was spent on the first two activities, and ~80 min was spent on the third activity. The first two activities were tutor led and aimed to revise the basis of action potentials and neurotransmitter release as covered in the first year of the degree. Both of these activities required students to place, in order, a randomized list of individual statements detailing the processes underlying action potentials (Table 1) and the sequence of events at a synapse (Table 1), topics with which they should be fully familiar. After the successful completion of these activities, students were asked about the different points at which it was possible to alter transmission (synthesis, storage, release, binding, breakdown, and reuptake) and asked to apply these changes to hypothetical synapses, e.g., “What would be the effect of increasing release of excitatory transmitter A on the postsynaptic neuron?” These questions were aimed at unpicking the process of synaptic transmission and emphasizing the idea that intervention could occur at many points.

Students were then split into three groups for the third activity. Groups were formed according to where students sat within the room; they were asked to turn the chairs around to face the peers sitting closest to them. This method was chosen to minimize disruption and most commonly resulted in students working within their college groups and, therefore, with students with whom they were familiar. This would ordinarily result in students with a range of abilities working together; however, this was not directly arranged or confirmed. This third activity was designed to be student led and to ensure both subject-specific learning and familiarization with using primary research articles as sources of information. Student groups were given sets of resources to collect information on neurotransmitter synthesis, breakdown/removal, major pathways, receptors, and clinical relevance. A variety of articles were chosen for each neurotransmitter (Fig. 1), including primary research and review papers as well as abstracts. Where a review paper was used, in the interests of time, the paper was marked up such that students were directed to the relevant sections. Abstracts were used entirely for clinical relevance as these allowed students to gain an understanding of the breadth of the clinical relevance of a neurotransmitter without having to read vast swathes of information. It also meant that the students had all the relevant details should they wish to access the full article at a later time. One of the most important criteria in selecting the papers was the readability of the material. As second-year undergraduates, students had little experience with primary research papers, which will later be...
order. Rapid removal of the transmitter from the cleft follows to ensure spatial and temporal specificity to the transmitter. This removal is either in the form of

The transmitter rapidly diffuses across the cleft to bind with transmitter-gated ion channels.

Transmitter vesicles transiently fuse to the membrane and release their contents into the cleft (exocytosis).

An action potential triggers the influx of Ca\(^{2+}\) into the nerve terminal.

The empty vesicle is recaptured (endocytosis) and fuses with the larger endosome membrane. New vesicles buff off the endosome to take up new transmitters with the aid of specific transport proteins.

The neuron becomes hyperpolarized below the resting membrane potential. The membrane potential repolarizes.

Critical for practicing evidence-based medicine, and, as such, it was important to find challenging and yet accessible material.

It was explained to the students that they would be given time to collate the information on the specific neurotransmitters that the group was given to study before reporting back to the entire class by completing a table of information on the board. To ensure an equal workload for the groups, the neurotransmitters being investigated were split up and given to groups to study in pairs as follows: glutamate and norepinephrine, serotonin and ACh, and GABA and dopamine. The term “equal workload” has been used to describe the amount of reading necessary to extract the information required. The number of research articles required to gain all the information that the students needed for a neurotransmitter varied; for example, four articles and six abstracts were given to students studying glutamate, whereas students studying dopamine had three concise articles that included all the relevant information. For this reason, it was not suitable to split the seminar into six groups and have each group study a different neurotransmitter, as the amount of reading required by the six groups would have varied. Therefore, three subgroups were used so that the average reading required for both the neurotransmitters studied by individual groups was similar. In addition, norepinephrine and ACh were separated so that one group did not only encounter familiar topics.

Throughout the group work, the tutor kept close watch on student progression and was available to clarify or assist where necessary. During this third activity, 20 min was given for literature study by the subgroups followed by 20 min for the subgroups to report back to the rest of the main group on their selected neurotransmitters. Once this was completed, a handout version of the table, prepared by the tutor, was given to all students for their prior knowledge of the six transmitters studied in the seminar and their previous experience of using primary research papers for study. Students rated their prior knowledge of the six neurotransmitters as 2.8 ± 0.82 (of 5 total), indicating that students felt they had some knowledge of the neurotransmitters. Their prior usage of research papers was slightly lower and more varied, with a rating of 2.6 ± 1.23.

Students were given a pack of cards containing each statement on a separate slip of paper mixed in random order and asked to place the statements in the correct order.

### Table 1. Statements used during activity 1 and activity 2 to revise action potential and neurotransmitter release mechanisms

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>
| Voltage-gated Na\(^+\) channels open, and Na\(^+\) moves into the cell due to concentration and electrical gradients. | ![](http://advances.physiology.org/)

Data were analyzed using percentages of ratings and mean scores for numerical data. Single-factor between-measures ANOVA was used to analyze differences between knowledge gained when students directly studied the neurotransmitter and compared with when they were presented with the information during the plenary by another student group. Comments made in response to the final question were categorized into main themes, and the frequency of reporting was calculated as a percentage of the overall comments made.

It should be noted that the Medical Sciences Divisional Ethics Committee at Oxford University did not require ethical clearance for this study because an anonymous questionnaire was used to collect feedback on teaching methods only and not personal information. Indeed, within the university it is commonplace for such courses to provide a questionnaire at the end to create a feedback cycle to improve pedagogy, and, as such, ethical approval was not required.

### RESULTS

Of the 78 students in attendance, 76 students completed evaluation and the remaining 2 students had to leave the seminars early.

**Students had some prior knowledge but varied use of primary articles.** The questions shown in Fig. 2 focused on student experience in using primary research articles to help them study. Questions 1 and 2 (Fig. 2) specifically assessed students their prior knowledge of the six transmitters studied in the seminar and their previous experience of using primary research papers for study. Students rated their prior knowledge of the six neurotransmitters as 2.8 ± 0.82 (of 5 total), indicating that students felt they had some knowledge of the neurotransmitters. Their prior usage of research papers was slightly lower and more varied, with a rating of 2.6 ± 1.23.
The majority of students found using articles easy and useful and would use them in future. Question 3 (Fig. 2) asked whether the students found using the articles to further their knowledge easy. Perhaps unsurprisingly, 18% either disagreed or strongly disagreed that using the papers was easy. A further 36% neither disagreed nor agreed that it was easy, with the remaining 46% either agreeing or strongly agreeing that using the papers was easy. Question 4 (Fig. 2) asked whether the student had found using the papers useful in developing their knowledge. Seventeen percent disagreed or strongly disagreed that the papers were useful, whereas 20% had no feelings either way. An impressive 63% reported finding the papers useful in developing their knowledge. To evaluate whether the use of articles in this structured form would increase the likelihood of students using papers in the future, question 5 (Fig. 2) asked students to rate their agreement with the statement that they were likely to use articles in their study in future. Fifty-five percent of the students agreed or strongly agreed that they would use articles in future. A further 28% were unsure, and the remaining 17% felt that they would not use articles in future.

Student knowledge increased more for less familiar material and as a result of direct study. Students were then asked to record which transmitters they studied directly in the seminar and rate how much their knowledge of all the individual transmitters increased as a result of the seminar. Scores awarded were separated according to whether students studied the transmitter within their group (in group) or were taught it...
by their peers (by peers), as shown graphically in Fig. 3A. To establish whether students felt their knowledge increase was greater for the transmitters studied in group compared with by peers, we compared the ratings using single-factor between-measures ANOVA. Of the 76 students that completed the evaluation, 62 students completed all the relevant sections for this analysis and were therefore included.

Across all groups, over 70% of all students agreed or strongly agreed that their knowledge of glutamate, serotonin, GABA, and dopamine increased during the seminar, regardless of whether they had been taught it within their group or by their peers (Fig. 3B). Conversely, only 20–50% of students agreed or strongly agreed that their knowledge of ACh and norepinephrine increased (Fig. 3B). Indeed, whereas only 0–5% disagreed or strongly disagreed that their knowledge of glutamate, serotonin, GABA, and dopamine had increased, 8–39% disagreed or strongly disagreed that their knowledge of norepinephrine and ACh had increased (Fig. 3B). All neurotransmitters were awarded a slightly higher average score by students who studied the transmitter directly compared with those who were taught the information by their peers (Fig. 3A); however, this difference was not significant for dopamine ($F_{1,61} = 2.46, P = 0.12$), glutamate ($F_{1,61} = 0.12, P = 0.72$), norepinephrine ($F_{1,61} = 2.76, P = 0.10$), and ACh ($F_{1,61} = 2.08, P = 0.15$). A significantly higher average score was awarded to serotonin ($F_{1,61} = 9.46, P = 0.003$) and GABA ($F_{1,61} = 5.51, P = 0.02$) by students who directly studied the information compared with those taught by their peers. Taking an average of the scores awarded for all neurotransmitters, 3.9 ± 0.64 was awarded for neurotransmitters taught in the group compared with 3.58 ± 0.72 when taught by peers ($F_{1,374} = 12.8 P = 0.0003$) showing that, overall, although the majority of students felt that their knowledge increased, for four of six of the neurotransmitters studied, students learned more when directly reading the material compared with being taught it by their peers.

The final open question allowed students to offer any further comments on the seminar. Of the 76 students who completed the evaluation, 20 students offered further comments (Table 2). Of these 20 comments, 19 comments could be divided into 4 main themes: 4 comments related to the repetition of ACh and norepinephrine from the first year, 3 comments related to the length of the seminar, 4 comments related to the lack of preparatory reading, and 8 comments that were entirely positive and reported the seminar to be effective and even enjoyable.

**DISCUSSION**

Overall, the results demonstrated that the use of original research articles in teaching synaptic pharmacology was beneficial in terms of increasing student knowledge of the topics as well as increasing their likely future use of research papers. The results demonstrated that before the seminar, the students felt they had some knowledge of the transmitters, presumably through prior study during their first and second year. However, the seminar was effective at increasing this knowledge, particularly for dopamine, GABA, glutamate, and serotonin, and above ACh and norepinephrine. Open feedback suggests that this finding might have been due to the students having greater knowledge of the latter two before the seminar, through comments backed up by the syllabus in both the first year and early stages of the second year. Although it might be expected that this prior knowledge should facilitate new learning, previous work has shown that instructors or tutors are often inaccurate in their assessment of students’ prior knowledge (9). It is probable that the amount of factual knowledge students had gained about these two neurotransmitters in the previous year of study was underestimated, which is likely to be, at least in part, not due to teaching the prior courses but due to the differences in college teaching at the university. For example, some 30% of students did report an increase in their knowledge of ACh and norepinephrine; it is possible that this 30% had less college tutorial support than the majority and therefore had less knowledge initially. In any event, it seems that the seminar was not pitched at a sufficient level to increase knowledge in a comparable manner with that found with the other transmitters. One way to protect against inadequate pitching in the future would be to set a quiz for students to help identify where the emphasis is needed. In the case of this specific course, it is likely that to facilitate improvements in knowledge of these two neurotransmitters, it may be necessary to increase the emphasis on clinical relevance, which is not dealt with earlier on in their degree.

Interestingly, the results suggest that for four of the six neurotransmitters studied, students had a shared learning ex-
experience, as indicated by the knowledge of neurotransmitters not directly studied increasing by a comparable amount with that reported for those that were directly studied. However, such comparable increases were not found for serotonin and GABA, where students who had not directly studied the information felt that they had experienced less knowledge improvement. Although there is no clear reason for this difference, we suggest that, certainly in the case of serotonin, it is likely to be a reflection of the complexity of the transmitter.

Supplemental Table 1 shows that the information available to students on serotonin receptors, for example, would have created an accurate and yet incomplete picture as a vast number of receptor subtypes have been identified but as yet selective drugs are lacking. Although we would not have expected the same to be true for GABA, the lack of shared learning for this transmitter may relate to the amount of clinical information presented for GABA, which was comparable with norepinephrine and ACh, both of which students had encountered before, meaning that the amount of new clinical information was highest for GABA. In future studies, it will be useful to ascertain a more detailed breakdown of where students felt knowledge had or had not improved.

Before the seminar, usage of research papers was reported as reasonably low and quite varied. The variation is perhaps unsurprising, given that such papers are most likely to be used in tutorials, which vary across colleges and individual college tutors. After the seminar, the majority of students reported that using the papers was easy and useful, which is likely to have directly contributed to 55% of them reporting that they would use research papers again in future. Obviously in this instance students were not expected to source the papers themselves; however, given the skill and perseverance involved in effective literature searching, we feel that demonstrating the value of such papers will help motivate students to use them in the future—an idea backed up by the data. Furthermore, we feel that the students received the papers so well because of the nature of the content being studied. First, the content was not entirely new, and, therefore, students could be challenged by the teaching method, where challenging with both method and content may be counterproductive. Second, pharmacology for
In conclusion, we have developed an effective method for increasing knowledge of synaptic pharmacology using primary research resources, which, for the most part, resulted in a shared learning experience for the students. The student-led session allowed students to work in small groups to research the characteristics of neurotransmitters from specific research papers. Students then contributed this information to a plenary session. The seminar received favorable feedback, with the majority of students agreeing both that their knowledge had increased and that they would use research articles for study in the future.

Of the 76 students, 20 students left comments, which were separated into five categories: repetition of ACh and norepinephrine (NE) information from the first year, negative remarks regarding the length of the seminar, negative remarks regarding the lack of preparatory reading, positive remarks, and miscellaneous. The percentage of comments from each category is also shown.

<table>
<thead>
<tr>
<th>Comment</th>
<th>Percentage of Total Comments Relating to Each Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetition of ACh and NE information from the first year</td>
<td>20</td>
</tr>
<tr>
<td>Already knew about ACh and NE.</td>
<td></td>
</tr>
<tr>
<td>Already knew about ACh and NE.</td>
<td></td>
</tr>
<tr>
<td>Already knew quite a bit on ACh and NE.</td>
<td></td>
</tr>
<tr>
<td>ACh stuff was a little repetitive.</td>
<td></td>
</tr>
<tr>
<td>Negative remarks regarding the length of the seminar</td>
<td>15</td>
</tr>
<tr>
<td>It was difficult but useful. Also, too long.</td>
<td></td>
</tr>
<tr>
<td>Too long spent reading articles; could have come to discussion earlier.</td>
<td></td>
</tr>
<tr>
<td>Too long— one hour is sufficient; just recovered lecture material; Ian Devonshire was enthusiastic and helpful.</td>
<td></td>
</tr>
<tr>
<td>Negative remarks regarding the lack of preparatory reading</td>
<td></td>
</tr>
<tr>
<td>We were not given any preliminary work to do—okay if none needed, but we were rather confused beforehand as to whether we needed to do any.</td>
<td></td>
</tr>
<tr>
<td>It would have been useful to be given some reading/research to do beforehand— I tried to do some but &quot;synaptic transmission&quot; is quite a broad topic.</td>
<td></td>
</tr>
<tr>
<td>[It would have been useful to have] information on seminar content before [the] seminar to do reading and get more from the seminar.</td>
<td></td>
</tr>
<tr>
<td>Would have been much better if we had been given work to prepare/reading before hand. Otherwise very good.</td>
<td></td>
</tr>
<tr>
<td>Positive remarks</td>
<td>40</td>
</tr>
<tr>
<td>[It was] good getting into groups.</td>
<td></td>
</tr>
<tr>
<td>I liked it.</td>
<td></td>
</tr>
<tr>
<td>More please.</td>
<td></td>
</tr>
<tr>
<td>Very effective.</td>
<td></td>
</tr>
<tr>
<td>Good.</td>
<td></td>
</tr>
<tr>
<td>Enjoyable, detailed, reminder of work done at the beginning of term.</td>
<td></td>
</tr>
<tr>
<td>Very useful.</td>
<td></td>
</tr>
<tr>
<td>Very good, thanks.</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5</td>
</tr>
<tr>
<td>Difficult to write down information when presented in this format</td>
<td></td>
</tr>
</tbody>
</table>

Medical students sit at the border between basic and clinical sciences, and this border is clearly demonstrated by the use of up-to-date, ever-changing primary research papers. Although we did not assess this in the present study, we feel that such a suitably gentle and supervised introduction to research papers may also serve to enthuse students to engage with research directly in their future studies and careers.

Finally, the open comments made by the students provided useful feedback on how the use of literature could be improved in this context. A minority of students requested that the resources be made available ahead of the seminar. The tutors purposefully did not provide the students with reading material beforehand as part of the exercise to encourage the students to work together to quickly identify the important information in the research articles; it was not intended for the students to read all the material available. Being able to identify the main points and summarize any form of reading material is an important skill that this exercise was attempting to encourage, as well as emphasising the vast amount of information that is often available on a subject that textbooks cannot cover in detail. For future work however, reading material could be posted on the university website, which would allow students attending a particular seminar to download resources beforehand. Although we feel this is a possibility, given the desire to make the learning a shared experience, it would be important to ensure that this prior reading did not impact on the discussion during the seminar. A small number of students also commented that the seminar was too long. These seminars have always been scheduled for 2 h, but, in previous years, they have finished ahead of time, and it is therefore possible that the students were expecting to finish early. Given the amount of reading and discussion in the seminar, it is unlikely that it could be much abbreviated, but it is of course critical that the tutor monitors progress and draws all groups together for discussions at the earliest suitable point.

If this project were to be repeated, it could be altered to increase the clinical relevance if necessary, while still allowing students to engage with primary literature. For example, students could be directed to more easily read resources (undergraduate text books) for basic information such as neurotransmitter synthesis. This would allow them to access this information, which is in some cases revision, faster, thus leaving more time for focusing on clinical relevance using research papers. Given the importance of the plenary in developing a shared learning experience, students would still be required to report back to the group but with a heavier emphasis on specific clinical disorders.

In conclusion, we have developed an effective method for increasing knowledge of synaptic pharmacology using primary research articles, which, for the most part, resulted in a shared learning experience for the students. The student-led session allowed students to work in small groups to research the characteristics of neurotransmitters from specific research papers. Students then contributed this information to a plenary session. The seminar received favorable feedback, with the majority of students agreeing both that their knowledge had increased and that they would use research articles for study in the future.
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DISCLOSURES

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