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INSTRUCTIONAL DESIGN AND ASSESSMENT

Simulated Drug Discovery Process to Conduct a Synoptic Assessment of Pharmacy Students

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Objective. To implement and assess a task-based learning exercise that prompts pharmacy students to integrate their understanding of different disciplines.

Design. Master of pharmacy (MPharm degree) students were provided with simulated information from several preclinical science and from clinical trials and asked to synthesize this into a marketing authorization application for a new drug. Students made a link to pharmacy practice by creating an advice leaflet for pharmacists.

Assessment. Students' ability to integrate information from different disciplines was evaluated by oral examination. In 2 successive academic years, 96% and 82% of students demonstrated an integrated understanding of their proposed new drug. Students indicated in a survey that their understanding of the links between different subjects improved.

Conclusion. Simulated drug discovery provides a learning environment that emphasizes the connectivity of the preclinical sciences with each other and the practice of pharmacy.

Keywords: synoptic assessment, drug discovery, integrated learning, simulation

INTRODUCTION

Pharmacy education is underpinned by a broad range of preclinical sciences. Information from apparently disparate scientific disciplines must be considered when a new drug is developed, yet pharmacy students may fail to recognize the interdependency of these disciplines. For example, the chemical structure of a drug determines its pharmacodynamic activity and, hence, its potential therapeutic use, but also its physicochemical and pharmacokinetic properties. All of these factors must be considered when choosing a dosage form. In contrast, many pharmacy degree programs, including that previously taught at Keele University, have a modular structure. This compartmentalization of information has been associated with fragmenting information and obscuring the interrelationship of different subject areas.[1] Indeed, the United Kingdom's General Pharmaceutical Council (GPhC) advises that "curricula must be integrated."[2] Integration is also emphasized in several of the Accreditation Council for Pharmacy Education (ACPE)[3] standards for doctor of pharmacy (PharmD) accreditation, including standard 9 (integrating learning with practice), standard 10 (integrating content and competencies across disciplines), and standard 15 (using teaching and learning techniques to promote integration). Discipline integration has been described as a "paramount educational strategy" in pharmacy education,[4] but integrated learning does not happen spontaneously and must be catalyzed.[5] Several exercises to encourage integration of science with pharmacy practice have been proposed,[6-10] but relatively few also address the relationship of the scientific disciplines. This has prompted faculty members at Keele University to redesign the course, moving from a modular course structure toward more integrated learning. As part of this, we have developed an exercise that requires students to consider the relationship between the different subject areas taught in the second year of the 4-year accredited master of pharmacy (MPharm) degree program. Our goal was to encourage students to integrate information from an entire academic year, making links between the different disciplines.

To explain the context in which we deployed this synoptic assessment, we first briefly summarize the second year of the pharmacy degree program at Keele. Principles of pharmacology are covered in more detail during

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the second year, along with pharmacokinetics, drug metabolism, toxicity, and safety testing. While pharmaceutics is embedded across the 4 years of the MPharm program, it is addressed in detail in the students' second year in the context of the formulation, manufacture, and quality assurance testing of a wide range of pharmaceutically relevant dosage forms. It therefore constitutes a significant part of the synoptic exercise. Analytical methods used in medicinal chemistry are introduced in the first year of the course and students use infrared spectroscopy routinely to confirm the presence of functional groups. In the second year, ^{1}H and ^{13}C nuclear magnetic resonance spectroscopy and mass spectrometry are covered in some detail, and drawing on this and their knowledge of infrared spectroscopy from the previous year, students are expected to identify the structure of simple molecules from the spectra alone.

"Synoptic assessments" encourage students to make connections between different elements of a subject.[11] They have previously been used effectively to encourage an integrated approach to learning in computer science.[12] We have developed a synoptic assessment comprising a small group exercise that simulates the discovery and development of a new drug, drawing on data from several subject areas and culminating in the writing of an abbreviated marketing authorization application (MAA) for review by a regulatory authority. The intended learning outcome is that students understand how data from disparate disciplines are integrated and how this affects the clinical use of a drug. To link the exercise explicitly to pharmacy practice, students also prepared an "information for pharmacists" leaflet describing the new drug. We aligned[13] the final assessment of the exercise with the intended learning outcomes; students were advised that they must consider the integration of the data from different subject areas to pass the final assessment. Compartmentalized knowledge of individual areas was inadequate to pass the assessment and students had to demonstrate an understanding of the links between different subjects.

DESIGN

The exercise was conducted in academic years 2010-2011 (84 students) and 2011-2012 (97 students) at Keele University School of Pharmacy. Groups of 5 to 6 students were each assigned to conduct a drug discovery program using a fictitious drug molecule from a fictitious pharmaceutical company. Drugs were referred to by a company drug number (eg, PPX-107324) and students were provided with information about the molecule in each of the subject areas studied during the second year of their degree program. Students were instructed that their goal was to use the data to simulate the discovery and development of the drug and to write a marketing authorization application for a proposed therapeutic use of their drug by the end of the academic year. The data were delivered to the students in batches throughout the academic year (Figure 1). Students proposed a therapeutic use for their drug after they analyzed the data provided. This required the students to read the scientific literature to understand the drug targets described in the assays. Students were supported in this with a teaching session in which they learned how to read scientific publications. Although the students were free to propose any use of the drug they wished, the pharmaceutical and pharmacological activities of the drug only offered a limited number of potential therapeutic applications. Each batch of data was released after the students were taught the corresponding subject area. Formative feedback sessions in which the students presented their preliminary analysis of the data and received feedback from members of the teaching staff were also scheduled throughout the year.

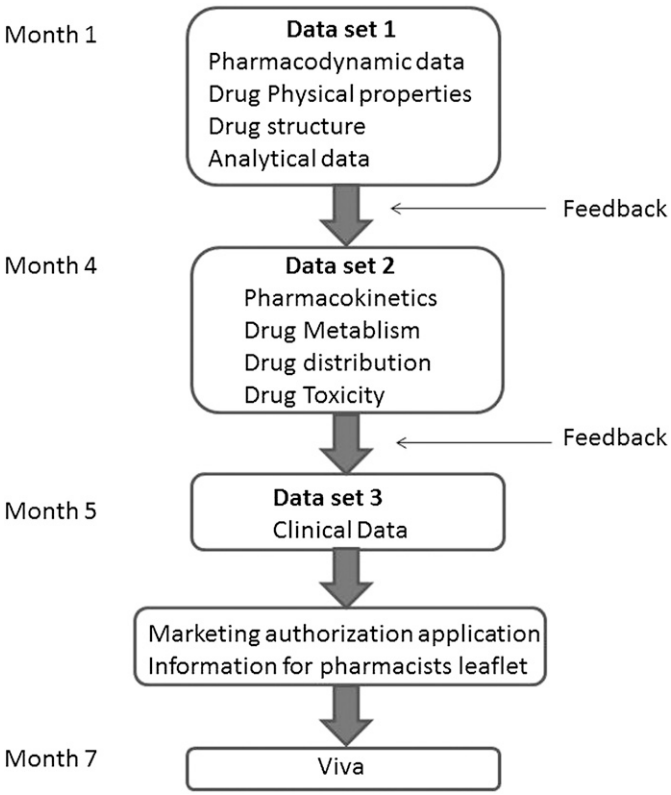

Figure 1. The flow of data presented to students.

Data Set 1

Data set 1 involved pharmacology, pharmaceutics, and medicinal chemistry. We prepared a summary of the drug properties as we created the data to serve as a marking aid for the final assessment. To generate the data for

the projects, a search of the scientific literature was conducted to identify new drug molecules and their targets. The structures of the drugs were modified to match the physical and pharmaceutical properties we desired or so that the analytical data were not too complex.

Pharmacology. The published experimental assays that had been used to develop the drug molecule were used to create the pharmacology data sets. Assays using isolated proteins, intact cells, and whole animal assays were identified from the literature and data generated for each of these. An Excel spreadsheet was formatted to automate the creation of dose-response curves (from 10^{-10} to 10^{-5} M, with simulated experimental error), requiring entry of only the desired minimum and maximum response and the desired half maximal effective concentration (EC_{50}) or half maximal inhibitory concentration (IC_{50}). The students were provided with data for the assays together with a brief description of the experimental procedure. The drugs were also endowed with additional activity at related receptors (eg, related G-protein coupled receptors) to raise the possibility of drug toxicity and introduce the concept of therapeutic window. Students also received data indicating the performance of their group's drug in all the assays used in the different projects, comprising 110 isolated protein assays, 122 cellular assays, and 45 assays in mice in total. For intracellular targets, the potency of the compound in isolated protein assays (eg, enzyme assays, receptor binding) was generally chosen to be greater than that in the cellular assays to reflect issues of drug penetration into cells. Animal data simulated pathophysiological measurements of disease models in mice. To ensure consistency, the drug dose that caused a therapeutic effect was compatible with the subsequent pharmacokinetic data (see below) and the drug concentrations required for activity in the cellular assays.

Pharmaceutics. Students were provided with key pre-formulation information pertaining to their drug. This included solubility (aqueous solubility, solubility in non-aqueous solvents, logP), ionization (pK), and other physical properties that were specific to a particular drug and which may affect its chemical and/or physical stability. Data for the chemical stability of the drug were also provided. In some projects, an issue was introduced, such as degradation in a particular solvent or by another mechanism such as oxidation.

Medicinal Chemistry. The chemical structure of the drug molecule was provided to students, together with tabulated ^{1}H nuclear magnetic resonance (NMR) and infrared data. For infrared data, students were required to identify the functional groups likely to correspond to the infrared signals. For ^{1}H NMR spectroscopy, students were asked to assign each proton environment to a given signal while also considering the reported multiplicity and integral value for each chemical shift value that was tabulated. Students were also asked to predict the appearance of the corresponding ^{13}C NMR spectrum and identify possible fragmentation mechanisms to predict mass spectrometry data. Lastly, students were encouraged to suggest other analytical data that would help them confirm the structure and purity of the drug candidate.

Data Set 2

Data set 2 covered pharmacokinetics and metabolism, drug distribution, and toxicology.

Pharmacokinetics and Metabolism. Data were provided as drug concentration in plasma following both intravenous and oral administration to mice. An Excel spreadsheet was written to facilitate the production of this data set. The pharmacokinetic data were linked to the animal and cellular data; the dose of drug that gave a therapeutic effect in animal models in the first data set afforded a plasma concentration that exceeded the IC_{50} or EC_{50} of the drug in cellular assays. This allowed students to integrate the different sets of information. In some cases, pharmacokinetic data were provided indicating the drug had little oral bioavailability, and this might be rationalized by reference to the structure of the drug molecule and its physicochemical properties. If the drug had inadequate oral bioavailability, students could request data for an alternative route of administration. However, this route had to be consistent with the desired therapeutic use of the drug and the pharmaceutical properties of the drug. In other cases the drugs were assigned particularly short half lives, forcing the students to consider how best to administer and formulate the drug. In cases where the students were assigned a pro-drug project, the pharmacokinetic data showed that the drug had poor oral bioavailability but was readily detected in plasma after administration of the pro-drug.

Students were asked to consider the structure of the drug molecule, and propose the 3 most likely phase 1 metabolites. They were given freedom to decide whether the drug would undergo phase 2 metabolism, but were instructed to consider the structure of the drug and any foregoing phase 1 metabolism.

Drug Distribution. Students were provided with drug distribution data, expressed as the fraction of the drug found in each particular tissue following administration of a single therapeutic dose to a mouse. Data were also provided indicating whether the drug was excreted in breast milk and whether it crossed the placenta in pregnant women.

Toxicology. Data were provided that reflected the preclinical safety tests recommended by the international conference on harmonization,[14] including safety pharmacology, reproductive toxicity, genotoxicity, and carcinogenicity. Where possible, the results were linked to any off-target effects that had been introduced into the pharmacology data. For example, some compounds inhibited hERG channels and this was reflected in Q_t prolongation in the safety pharmacology data. Where serious adverse effects were noted, these were reported at doses significantly above the therapeutic dose to provide a therapeutic window.

Data Set 3

Data set 3 contained clinical data. To simplify the production of data describing the clinical evaluation of the drug, students were asked to predict the results that might be obtained in phase 1, 2, and 3 clinical trials, bearing in mind that this should reflect the preclinical data that they had already received. For the purposes of generating these data, students were provided with a suitable allometric scaling factor to convert the therapeutic dose anticipated from animal studies to a crude estimate of what might happen in human subjects.

For the final report, students were asked to complete an abbreviated marketing authorization application (1 per group) using a template based on guidance from the European Medicines Agency on preclinical aspects of an MAA.[15] This required information on the drug's structure, pharmacodynamics, pharmacokinetics, metabolism, stability, formulation and administration, safety and toxicology, drug interactions, how quality was ensured, and the results of clinical trials. Students were also required to synthesize the collected data into an "advice to pharmacists" leaflet, based on those available from the Royal Pharmaceutical Society's website.[16] This included several elements: what the medicine was indicated for; mechanism of action; the main cautions and contra-indications; the dose and how it should be administered; adverse effects; drug interactions; storage requirements; and where to direct patients wanting further information. Students were given the option to add further subheadings if they wished.

EVALUATION AND ASSESSMENT

We elected to assess the exercise by oral examination. We allowed students to attend the oral examination as a group, but they were asked questions individually to ensure they had considered the entire data set and integrated the information. Students were allowed to bring their group's MAA and guidance to pharmacists documents for reference. We used the principle of constructive alignment and advised the students that they would not be able to pass the oral examination unless they understood the integration of the data. Four members of the teaching staff from different disciplines attended the examination, the outcome of which was a grade of pass or fail. Students were individually asked 4 questions testing integration (Table 1). To pass the evaluation, students were required to demonstrate integration of knowledge in at least 2 of the 4 questions posed; integration was considered to be achieved if students could logically link data from 2 or more of the multiple disciplines represented by the content in each question (Table 1). Students failed the assessment if they could not demonstrate integration of subject areas in response to at least 2 of the questions, even if they demonstrated understanding of the underlying individual subject areas. If students did not satisfy the examiners, they were offered the opportunity to sit for the examination again the same day, with a separate set of examiners. This was not considered an additional attempt at the examination but rather a "second grading." Failure as confirmed by the second grading, led to a loss of 5% of their overall grade for the entire year and students were not permitted to progress to the next academic year until they passed the assessment. To confirm our observations from the evaluation, we conducted a survey in both years using a series of questions answered on a Likert scale, with space provided for students to freely make additional comments.

In 2 successive academic years, the majority of students demonstrated integrated learning - (81 of 84 [96%] students passed in 2010-2011, 78 of 97 [80%] students passed in 2011-2012).

A 33-item survey instrument was administered to students at the end of the course. Students felt that the primary integrated learning objectives had been met (Table 2). The students agreed or strongly agreed (54% in 2010-2011; 62% in 2011-2012) that the task "demonstrated the interdependency of the individual subject areas." The students believed it reinforced their understanding of individual subject areas (70 and 68%, respectively) and that it consolidated their learning (69% and 65%, respectively) (Table 3 and Table 4). They also felt that the task encouraged them to engage with the scientific literature in more depth (52% and 57%, respectively). The survey results for the 2 years were comparable except that in the 2010 cohort, the students felt they were not given sufficient time to complete the task. The students felt they had derived greater insight and confidence into a broad range of subject areas. The one exception to this was microbiology. In students' written comments on the survey instrument, integration, the primary learning objective, was listed as a positive feature of the exercise by 20% and 25%

Table 1. Examples of Integrated Questions Used in the Oral Examination[a]

Example Questions	Disciplines Integrated
What are the chemical stability issues with this drug, how have these been mitigated by the formulation/packing strategies and how does this explain the storage instructions which you have provided for pharmacists?	Medicinal chemistry, Pharmaceutics, Pharmacy practice
How has the route of administration been selected taking into consideration the drug's stability and its intended clinical use?	Pharmacokinetics, Pharmaceutics, Pharmacy practice
How does the structure of the drug affect its absorption, distribution, metabolism and elimination and how do these properties influence the clinical effects of the drug and the advice given to patients	Medicinal chemistry, Pharmacokinetics, Clinical trials, Pharmacy practice
Considering the intended use of this drug, how have the pharmacokinetic data been used to choose the dose, frequency and formulation that you have proposed and how does this affect the advice given to patients?	Pharmacokinetics, Pharmacodynamics, Pharmaceutics, Pharmacy practice
What drug interactions should pharmacists be alert for and how are these explained by the structure of the drug, the pharmacokinetic and/or pharmacodynamic properties of the drug?	Pharmacology, Pharmacokinetics, Medicinal chemistry, Pharmacy practice
How do the preclinical and/or clinical data explain the situations which pharmacists should be aware of that contraindicate the use of this drug?	Pharmacodynamics, Pharmacokinetics, Toxicology, Pharmacy practice
Which potential adverse effects of the drug might you advise a patient to be aware of, and how are these explained by the preclinical and clinical trial data?	Pharmacodynamics, Toxicology, Clinical trials, Pharmacy practice
How does the distribution of the drug influence its clinical use, considering the pharmacodynamic properties of the drug and its potential adverse events?	Pharmacodynamics, Pharmacokinetics, Toxicology, Pharmacy practice
How do the physical properties of the drug molecule influence its pharmacokinetic properties, its formulation and the clinical use of the drug?	Medicinal chemistry, Pharmacokinetics, Pharmaceutics, Pharmacy practice
How have analytical techniques been used to confirm the identity of the medicinal product and its metabolites in preclinical studies and clinical trials?	Medicinal chemistry, Pharmacokinetics, Clinical trials

[a] An integrated understanding of different disciplines (2nd column) is necessary to coherently answer each questions. All of the questions are not appropriate for every project, and suitable questions were selected considering the drug properties.

of the respondents in 2010 and 2011, respectively. Group work was mentioned as a positive aspect of the assignment by several students, although opinions varied between students in each year. In 2010, 42% of respondents stated that group work was a positive feature, but in 2011, this dropped to 16% of students. In the first year we conducted the assessment, 41% of respondents commented that the workload was too high or compressed into too short a period. In response to these comments, we adjusted the timing of delivery of the data, and the following year only 24% of the respondents considered the exercise to be an excessive workload. Finally, the mode of assessment was mentioned as a negative feature by 10% and 21% of respondents in 2010 and 2011, respectively. In general, these respondents considered the oral examination to be stressful.

DISCUSSION

We have used the drug discovery and development process as a paradigm to addresses the overarching integrated learning objective that students integrate an entire year's study of different preclinical sciences, with each other and with pharmacy practice. By making these connections, students gain a deeper appreciation of the contribution of each subject area to the development of therapeutics and how considerations from different areas must be balanced. The exercise may be adopted by other schools without drastic changes to the course structure. In addition to the primary ILO, the exercise also allowed the students to advance their understanding of each of the individual subject areas by learning independently to analyze data, apply it, and synthesize new data. However, we did not formally assess these latter outcomes.

Each project had particular additional challenges built into it and many of these forced the students to integrate the data to understand it. For example, one drug possessed a carboxylic acid and exhibited activity in enzyme assays but not in cellular assays; conversely the ethyl ester pro-drug was active in cellular assays but not in isolated protein assays. This encouraged integration of pharmacology, medicinal chemistry, and metabolism knowledge in the students' assessment of the drug. Another challenge required noticing that a drug which did not cross the blood brain barrier lacked adverse effects on the central nervous system. A further challenge was provided when drugs showed poor oral bioavailability, requiring students to consider alternative routes of delivery

Table 2. Students' Perception of the Value of the Synoptic Assessment[a]

	Likert Score (2010-2011, 2011-2012)				
	Strongly Disagree				Strongly Agree
	1	2	3	4	5
I was given sufficient information to allow me to complete the Synoptic Task	6, 5	16, 18	38, 24	27, 35	13, 19
I was given sufficient time to complete the Synoptic Task	26, 1	24, 19	16, 24	19, 25	15, 31
The Synoptic Task has allowed me to consolidate my learning from this academic year	10, 5	2, 9	21, 21	40, 38	29, 27
The Synoptic Task allowed me to demonstrate the breadth of my knowledge	8, 6	13, 16	24, 30	33, 31	22, 16
The feedback sessions helped me to complete the synoptic task	5, 5	11, 18	29, 28	26, 32	29, 18
The synoptic task encouraged me to read scientific literature other than text books	6, 3	15, 14	27, 27	31, 32	21, 25
The Synoptic Task was too difficult	5, 5	35, 23	37, 38	11, 26	13, 9
The Synoptic Task clearly demonstrated the interdependency of the individual subject areas in this year of study	3, 5	8, 9	35, 25	35, 39	19, 23
The Synoptic task reinforced my understanding of individual subject areas in this year of study	6, 3	5, 9	19, 21	43, 45	27, 23

[a] Students from 2 successive academic years were asked to rate their agreement on a 5-point scale with the following statements. The figures show the percentage of students who selected each Likert rating from 2010-2011 (63 respondents from a cohort of 84) and 2011-2012 (80 respondents from a cohort of 97). Data from each year are separated by a comma.

that were appropriate for patients suffering from the targeted diseases, and adjust their formulation accordingly. This required students to integrate data from pharmacology, pharmaceutics, medicinal chemistry, and pharmacokinetics. A major concern was to ensure the preclinical sciences were integrated with pharmacy practice. A key strategy to achieve this was to require the students to write an abbreviated marketing authorization application and an "advice to pharmacists" leaflet. This forced the students to juxtapose the various data sets in 1 document. In addition, specific strategies were used to force students to link the data to clinical practice. For example, students were advised that toxicity in preclinical studies students should inform the toxicity that should be monitored during clinical studies and potentially

Table 3. Students' Attitude to How the Synoptic Assessment Improved Their Insight[a]

	Likert Score (2010-2011, 2011-2012)				
The Synoptic Task has given me greater insight into:	Strongly Disagree 1	2	3	4	Strongly Agree 5
Drug discovery	2, 3	10, 11	29, 29	38, 38	22, 19
Drug development	0, 1	5, 6	30, 26	37, 50	29, 16
Drug formulation	0, 3	2, 6	24, 18	41, 54	33, 20
Pharmacodynamics	0, 3	6, 1	17, 21	38, 49	38, 26
Pharmacokinetics	0, 3	2, 5	19, 21	38, 43	41, 29
Drug safety testing	2, 3	5, 10	29, 30	35, 37	29, 20
Drug interactions	0, 3	3, 6	32, 25	40, 44	25, 23
Adverse drug reactions	0, 3	3, 3	25, 23	46, 54	25, 19
Toxicology	2, 3	3, 8	32, 28	37, 41	27, 22
Analytical methods	0, 4	5, 10	27, 33	44, 38	24, 16
Microbiology	13, 13	10, 20	34, 33	24, 24	19, 11

[a] Students were asked to comment whether they considered that their insight in several different areas was improved as a result of the synoptic task using a 5-point Likert scale. The figures show the percentage of students who selected each Likert rating from 2010-2011 (63 respondents from a cohort of 84) and 2011-2012 (80 respondents from a cohort of 97). Data from each year are separated by a comma.

Table 4. Students' Attitude to How the Synoptic Assessment Improved Their Confidence[a]

The Synoptic Task has given me greater confidence in:	Likert Score (2010-2011, 2011-2012)				
	Strongly Disagree 1	2	3	4	Strongly Agree 5
Drug discovery	0, 3	13, 15	30, 33	35, 39	22, 11
Drug development	0, 3	11, 10	29, 29	38, 43	22, 16
Drug formulation	0, 3	5, 10	25, 29	40, 39	30, 20
Pharmacodynamics	0, 3	5, 9	25, 23	37, 48	33, 19
Pharmacokinetics	0, 3	2, 13	29, 18	37, 48	33, 19
Drug safety testing	0, 4	6, 11	40, 33	30, 34	24, 18
Drug interactions	0, 4	6, 9	29, 25	35, 45	30, 18
Adverse drug reactions	0, 4	2, 13	33, 24	40, 41	25, 19
Toxicology	0, 3	5, 14	29, 33	44, 33	22, 19
Analytical methods	0, 5	8, 15	32, 30	37, 38	24, 13
Microbiology	6, 10	10, 16	40, 31	23, 31	21, 11

[a] Students were asked to comment whether they considered that their insight in several different areas was improved as a result of the synoptic task using a 5-point Likert scale. The figures show the percentage of students who selected each Likert rating from 2010-2011 (63 respondents from a cohort of 84) and 2011-2012 (80 respondents from a cohort of 97). Data from each year are separate by a comma.

the advice that pharmacists might need to provide to patients to alert them to potential side effects. This issue was particularly significant for drugs in which we deliberately provided a narrow therapeutic window. In other cases, the data precluded the use of the drug in certain patient populations. For example, some drugs crossed the placenta, and students were expected to caution or contraindicate the use of the drug in patients who were or planning to become pregnant. In other cases, the drugs exhibited pharmacodynamic activity that precluded their use in certain patients; for example, one drug increased blood glucose, and students were expected to advise pharmacists that the drug should be avoided in diabetes. Many projects could be linked to pharmacy practice through potential pharmacokinetic or pharmacodynamic drug interactions, and these were also expected to be addressed in the "advice to pharmacists" leaflet.

In addition to encouraging the students to integrating disciplines, the exercise afforded the opportunity to reinforce learning in individual subject areas, allowing us to address supplementary learning outcomes. Students had to interpret the data within each subject area before they could attempt to address the implications of those results. By selecting the format in which the data are provided, instructors could encourage students to improve a facet of the subject area. This could be either one particular skill or broader analytical thinking. For example, by providing dose-response data, students were forced to rehearse the determination of fundamental pharmacological parameters such as EC_{50}. Alternatively, if students were asked to predict the properties of a molecule (eg, the likely metabolites), they were encouraged to take a more holistic view of a particular subject area.

The exercise required an entire academic year to complete. During this time, we scheduled 2 feedback sessions to support the students' data analysis and to ensure that the students continually considered integration of knowledge being learned in their course. To allow students to learn from the experience of other groups, the feedback sessions were conducted in the presence of other students, building upon the peer learning inherent in group activities. In addition to these formal sessions, several groups needed additional support interpreting the data sets, and this was achieved by instructors meeting with the individual groups as necessary.

The assessment part of the exercise was designed to ensure that each student had fully engaged with the exercise. The students worked in groups to analyze the data and prepare reports, raising the possibility that students may have assigned parts of the workload to individual group members. This could have negated our goal of the students learning to integrate information. Therefore, we designed the final assessment, an oral examination, so that each student had to address the entire project. We considered the oral examination to be a particularly useful tool because it allowed a clear exploration of individual students' understanding, making us confident that each student had met the primary integrated learning objectives. Accurately grading an oral examination can be challenging, so to provide a robust decision-making process, all students who initially did not succeed in passing were also evaluated ("second grading") by a second set of examiners. Thus, students who failed this second rating as well were considered not to have met an acceptable standard by 8 academic staff members. Although this made us confident in our assessment procedures, a significant

fraction of the students found the oral examination to be a daunting experience.

We considered using the MAA and information leaflet as the means of assessment. However, some students failed to participate in the group exercise, and relied on their colleagues to complete these assignments. Which students completed the majority of the work would not be evident had the written material been the assessment. We also wished to retain the group nature of the exercise for several reasons, including that most students enjoyed this aspect of the assignment. Oral discussion of concepts with their peers was highly relevant to future discussions with fellow professionals and well-informed patients. Consequently, we have chosen to retain the oral examination as the preferred method of assessment to ensure each student has met the required learning outcomes.

One weakness of our study was that we were not able to compare the results of the oral examination to those of a cohort of students who did not participate in the exercise because not having a portion of the class participate in the exercise could have potentially disadvantaged them. Despite this, the robust nature of the assessment makes us confident that we have been successful in achieving the main integrated learning objective. Students were deliberately asked questions (Table 1) which did not focus on detail within disciplines, but which required them to make links between knowledge learned from different disciplines. Students could only pass the assessment if they integrated the information, and the high pass rate for the examination confirms that a large proportion of the students achieved the integrated learning objective. This conclusion is strongly supported by the students' survey responses. A clear theme from the survey responses was that the students considered that the task helped integrate the data, but also improved their understanding of individual subject areas. Other unanticipated benefits were noted, including some students remarking that they enjoyed the problem-solving aspect of the project.

Integrated learning does not occur spontaneously and needs an active process, facilitated by instructors, for it to occur.[5] Several approaches have been presented where 1 or 2 disparate disciplines are integrated, often supported by appropriate scheduling of teaching sessions. However, many of these exercises only integrate a limited number of disciplines, compared to the broader integration achieved by the exercise we have developed. There are several examples of courses teaching drug discovery,[17] but to our knowledge this is the first example where it has specifically been used to promote integrated learning. This exercise may be used by other colleges and schools of pharmacy to promote curricular integration. To facilitate this, a sample data set is available from the authors on request.

There are some issues associated with this exercise. In particular, development of the projects required considerable staff time. However, the projects have been designed around a common core of data from the disciplines taught during the year, and we found that after writing a few projects, it became increasingly straightforward to create subsequent ones. It is also important during the development of each project that instructors ensure the projects are internally consistent. For example, if a drug is described as poorly soluble or chemically unstable, its structure should reflect these properties. Finally, to provide realism, the exercise also benefits from having instructors who have experience in conducting drug discovery. Although we believe that we have demonstrated that the exercise has promoted integrated learning, we have not assessed whether this improves overall performance of the students as pharmacy practitioners. However, educators have argued that integrated learning offers numerous valuable outcomes, making aligning pharmacy education and practice an important goal.[4]

SUMMARY

An exercise using the drug discovery process as a learning paradigm was successful in encouraging pharmacy students to integrate preclinical science concepts with pharmacy practice. Pharmacy students felt that it was an enjoyable exercise that improved their understanding of the links between different subject areas that must be considered in developing a drug. We hope that our work will stimulate other schools of pharmacy to consider this methodology to promote curricular integration so it may be evaluated more widely.

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