Research article

Differential white cell counts: an e-learning resource

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E-learning encourages positive student attitudes and has been shown to have a positive effect on the process of learning. Undergraduate nursing students at the University of Manchester are not provided with any practical haematology experience in their first year, and receive only a single lecture specific to white blood cell structure and function. The aim of the project was to produce an interactive e-learning resource to increase student knowledge of the five major types of white blood cell and the differential white cell count. The production of the resource followed the ADDIE instructional design model with phases of Analysis, Design, Development, Implementation and Evaluation. A scenario-based approach was used in the design phase to illustrate the importance of the different white blood cells in a clinical setting. The development of the resource in Opus Professional allowed interactive features to be incorporated. The null hypothesis stated that the resource would not cause a significant improvement in student knowledge of this area. Assessment questions testing student knowledge were completed by randomly selected participants from the target audience assigned to two independent groups. The pre-resource group (n = 29) completed the questions without use of the e-learning resource or any alternative mode of teaching, whereas the post-resource group (n = 25) completed the questions after use of the resource. Scores from the pre- and post-resource groups were then compared in order to assess the effectiveness and functionality of the resource. Overall, there was a significant improvement in participant knowledge after use of the e-learning resource (Mann–Whitney U-test, U = 154.500, p = 0.000). This allowed the null hypothesis to be rejected and showed that the learning outcomes had been achieved. 92% of participants found the resource enjoyable while 84% thought that the resource was effective in improving their knowledge of this area. This confirms findings from other research that e-learning has positive effects on learning outcomes and that students enjoy this learning methodology.

Key words: e-learning resource, differential white cell counts.

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Introduction

Differential white cell counts are performed in conjunction with the complete blood count and represent one of the most common laboratory tests performed today,1 providing indications of infection and illness. The relative proportions of the different types of white blood cell present in the blood are found, with irregularities signifying possible disease or malfunction within the body, for example, certain types of leukaemia.2 Differential cell counts can today be carried out by automated machines, but despite their advantages, the identification of abnormalities in either appearance or number of cells requires a follow-up manual differential to be performed.3 This highlights the continued importance of the ability to recognize and distinguish between the different white cell types. Nurses are frequently challenged to obtain and evaluate all or parts of the complete blood count, and the interpretation of the differential can often be complex, taking into account many factors.4 George-Gay5 highlights the importance of the complete blood count stating that an ‘enhanced understanding of this laboratory test is essential to providing quality care’.

For these reasons, it seemed appropriate to create an interactive resource, illustrating the concept and importance of

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the differential count, targeted at first-year nurses who are naïve in their knowledge of this area. The nurses at the University of Manchester undertake a module in their first year entitled ‘Anatomy and Physiology’ in which two lectures are dedicated to a broad introduction of the formed elements of the blood; however, the students do not undertake any practical haematology in their first year. The resource was designed to supplement the knowledge gained from this lecture unit and offer a substitute for the absence of any practical haematology. It could also provide a solid basis for modules in subsequent years, and practical situations they would encounter in the workplace. Research into the existing resources available on this area showed that there was a wide range of accessible information about white blood cells and the differential count, both in books6–7 and on the Internet.4,9 However, the majority of this information is presented in the same conventional format, with little of the basic science incorporated into clinical scenarios or placed in context for understanding of its practical use. The intention of the resource was to provide this information in a more memorable and interactive manner, which would demonstrate the practical use of this information in the clinical settings that the nurses would be faced with.

An interactive scenario-based approach was used to aid problem-based learning, since research of the existing resources had already revealed there was a great deal of information available to students, but emphasized that not enough of it was presented in context of its practical use. The use of a scenario or problem to prompt students to enquire and interpret the information in a clinical setting, means that the knowledge acquired is more readily retained because it has been ‘acquired by experience and in relation to a real problem’.10 It also increases enthusiasm of the students and produces positive student attitudes as concluded in studies by both Prince11 and Major and Palmer.12 The learning philosophy behind the creation of scenario-based learning is that it provides a story in which the participants play a key role, a role they may need to perform in real life in the future. As students work through the scenario to achieve their task, they learn the critical skills required to accomplish their assignment successfully.13 Nurses in particular need to be able to apply their knowledge to practical/clinical situations and so it was more useful for the nurses to analyse the information in a clinical scenario, rather than as a standalone biology module. A review by Laschinger14 into experiential learning in nursing highlighted that ‘Kolb’s cycle of learning which requires the use of a variety of learning modalities appears to be a valid and useful model for instructional design in nursing education’, indicating the relevance of this theory to the target audience. Kolb’s learning theory originated from principles outlined by Dewey, Lewin and Piaget, whereby the general learning cycle consists of concrete experience, followed by observation, reflection and subsequent modification of behaviour in the next experience. Piaget’s theory of Constructivism suggests individuals construct new knowledge from their experiences.16 This theory underpins the design of the e-learning resource, in which the participant investigates a scenario, and then adapts their responses to the next scenario based on the information they have gained. Fleming and Mills17 suggest four sensory modalities used for learning that reflected the experiences of their students. These are categorized into Visual, Aural/Auditory, Read/Write, and Kinesthetic (VARK), and offer a simpler method to explain people’s different preferred ways of learning. The e-learning resource aimed to use a mix of these styles, since most people are a mixture of all styles as suggested by Kolb and not limited to a single preference.

The ADDIE instructional design model is a common framework for structuring projects for the development of learning materials.18 The phases of Analysis, Design, Development, Implementation and Evaluation are carried out in sequence. The production of the resource would follow this sequence to ensure all phases were completed successfully.

Overall, the main aim was to produce an e-learning resource introducing students to the five major types of white blood cell and the differential count to highlight their importance in health and disease.

The intended learning outcomes (ILOs) for the target audience are specifically defined below:

(i) Student will be able to identify the different types of white blood cell from their appearance in a blood smear.
(ii) Student can recognize the normal proportions of each type of white blood cell in a differential count and identify anomalies.
(iii) Student has knowledge of the main functions of the different white blood cells in the body.
(iv) Student can relate anomalies in the differential count to a broad diagnosis of possible diseases or malfunctions.

The null hypothesis was that the resource would not cause a significant improvement in student knowledge and understanding of white blood cells and the differential count. The hypothesis would be tested by comparison of the pre- and post-resource groups’ data to discover if there was significant difference in assessment scores due to the use of the resource.

Materials and methods

Analysis

The analysis phase involved investigation of the prior knowledge base of the target audience and identification of their needs. This was carried out by a short set of paper-based assessment questions (shown in Fig. 1) distributed to randomly
selected participants from the target audience who acted as the control group (pre-resource group). The target audience varied in age but were all educated to at least GCSE or A level standard. All participants were first-year undergraduate students, enrolled on BSc (Hons) Nursing. They had all received a specific lecture on white blood cell structure and function prior to completion of the assessment questions. None of the students had ever carried out a differential white cell count before. The students had ∼30 min to complete the questionnaires. The questionnaire included both questions to directly test their knowledge and questions to gain an insight into their opinions of a potential e-learning resource on this subject. The majority of the questions were multiple choice, since these could be scored simply and impartially. The aim of these questions was to not only analyse the participants’ current level of knowledge, but to determine what they themselves hoped to gain from the resource, and what they felt they needed or wanted the resource to incorporate. Student

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**Questionnaire**

For my final year project I am creating an e-learning package to help boost students’ knowledge of the different types of white blood cell and their functions.

Could you identify the correct cell type in these images from the options shown below?

a) Monocyte  
b) Lymphocyte  
c) Basophil  
d) Eosinophil  
e) Neutrophil  
f) Platelet

1) ........................................

2) ........................................

3) ........................................

4) ........................................

5) ........................................

6) What is the main difference between a granulocyte and an agranulocyte?

7) Select the cells you think belong to the granulocyte family.
   Neutrophil  Eosinophil  Basophil  Monocyte  Lymphocyte

8) Select the cells you think belong to the agranulocyte family.
   Neutrophil  Eosinophil  Basophil  Monocyte  Lymphocyte

9) Do you know the different functions of each of these white blood cells? Yes/No

10) Have you ever carried out a differential white cell count? Yes/No

**Figure 1.** Pre-resource assessment questionnaire incorporating needs analysis. Questions 1–9 and 11–18 were used again in the post-resource assessment, which also included several additional questions for evaluative purpose.
knowledge could be evaluated by scoring the questions and finding the average score of the target group. Of the 22 questions asked, it was possible to score 14 of these, with 17 marks available since some questions required more than one answer. Open questions required comments or suggestions from the participants, which were not scored but were considered when designing the resource.

Twenty-nine randomly selected students from the target audience completed the pre-resource assessment in order to represent the needs and current knowledge of the first-year nurses at Manchester University. The results helped to define the main aim of the resource which was to enhance the understanding of the differential count by improving the knowledge of white blood cells and their role in the body, through the production of an e-learning resource.

**Design and development**

The detailed flow diagram shown in Fig. 2 delineates the full layout and content of the resource. The design strategy ensured that the resource was interactive and required
audience participation in order to increase participant motivation. The general layout and appearance of the resource is shown in Fig. 3. The presentation was designed to be attractive yet simple in order to retain the attention of the audience while remaining easy to understand. The resource was designed to take ~20–30 min to maintain the attention of the audience, and for this reason, the content was kept to the essential points.

**Scientific content**
The key scientific points included in the resource were a basic introduction to the white blood cells and the differential
count. The five major types of white blood cell (lymphocytes, monocytes, neutrophils, eosinophils and basophils) were introduced in terms of structure and function and the different types of cell morphology were outlined with the use of images and clear bullet points. The terms granulocyte and agranulocyte were defined to allow the participant to categorize the different cell types according to their appearance in a blood smear. The use of the differential count in the diagnosis of patients was described with examples and case studies, and functions of the cells revealed upon investigation. Reasons for atypical differential counts were also presented in relation to the different cell types.

The scientific content was presented in a scenario-based manner, in which three patients are presented for examination in order to highlight the importance of the different white blood cells and their role in health and disease. There was a single path through the resource (illustrated in Fig. 2) in which candidates had to complete each page/section in sequence, in order for them to progress to the next stage. Sometimes questions/games were compulsory and the participant was prevented from moving to the next stage until they had completed it correctly.

Information was provided based on enquiry into the scenario. At several stages within the resource, comparison of normal differential values to patient data in order to identify abnormalities was necessary. This recurring process of comparison was used to ensure that the normal differential values would be retained by the user. In this way, the facts are presented as the user progresses through the resource, continually testing their abilities and requiring interpretation of the data for progression, enhancing understanding and retention of information.

The resource was designed with user interactivity as a principal feature throughout in order to facilitate learning through active enquiry. Questions within the resource were used to test the participant and provide positive or negative feedback. It also helped prompt participants to revise the content they had overlooked, ensuring that the learning outcomes were achieved.

Software choice
Opus Professional 6 (Opus) was used to create the resource.

Implementation
The resource was placed on the University of Manchester Blackboard system allowing the target audience access to the package.19 The resource with attached online assessment questions was completed by a different group of 25 randomly selected nursing students from the target audience.

Evaluation
The final stage of the process was evaluation of the resource, which would require collection, collation and analysis of results from both the pre- and post-resource assessments. The pre-resource assessment group acted as a control group from which scores were compared against those gained by the post-resource group. Resource evaluation was based on criteria derived from the ILOs for the target audience, with questions designed to test whether these outcomes had been achieved. The post-resource assessment questions were scored in the same manner as for the pre-resource assessments to provide scores out of 17. The additional questions relating to functionality were used to assess the usability of the resource.

Both descriptive and analytical methods were used to evaluate the data gained from the assessments. SPSS 15.0 for Windows was used to carry out a Mann–Whitney U-test on the pre- and post-resource groups’ assessment scores to find whether a significant improvement had been made. This test was selected since the data were
results of two independent unpaired groups was being examined.20

The functionality of the resource was evaluated by responses to questions incorporated into the post-questionnaire, asking students to rate different aspects of the resource according to a defined scale. Open-ended questions with space for comments were also important to gain an insight into their thoughts, likes and dislikes of the resource, and any additional aspects that could be included in the future.

Results

Needs analysis
When asked whether it would be useful to learn more about the white blood cells, 100% of candidates answered ‘yes’, showing that students were enthusiastic about the proposal of the resource.

Current knowledge of white blood cells
Pre-resource assessments given to the participants provided a median score for the 29 students of 5 out of the possible 17 marks, an average of just <30%. No participants scored above 11 points.

Effects on knowledge
The percentages of correct answers to each question pre- and post-resource are shown in Fig. 4. For all questions apart from Questions 5 and 17, there are a higher percentage of correct answers in the post-resource group, showing a general improvement in student knowledge after use of the e-learning resource. The median scores of the pre- and post-assessment questionnaires are compared in Fig. 5. The median score doubled after use of the resource increasing from 5 for the pre-resource group to 10 for the post-resource group. Figure 5 also shows the distribution of scores within each group. The inter-quartile range (IQR) for the pre-resource group is 4, whereas for the post-resource group, it is 5, showing a slightly wider spread of results for the post-resource group. The position of the median on the post-resource box and whisker plot in Fig. 5 indicates that the results are negatively skewed about the median, with 25% of the post-resource group above the median scoring either 10 or 11 points. A Mann–Whitney U-test performed on
the overall assessment scores of the pre- and post-resource groups showed that there was a significant improvement in overall assessment scores (Mann–Whitney U-test, $U = 154.500, p < 0.01$).

Each ILO was assessed more specifically by focusing on responses to certain sets of questions within the assessment.

**Student will be able to identify the different types of white blood cell from their appearance in a blood smear**

Questions 1–5 directly related to ILO 1. The scores (out of 5) for these questions in the pre- and post-resource groups were compared using a separate Mann–Whitney U-test, showing a significant improvement in this area alone (Mann–Whitney U-test, $U = 213.500, p < 0.01$).

**Student can recognize the normal proportions of each type of white blood cell in a differential count and identify anomalies**

Twenty-four per cent of students in the post-resource group thought they would know the correct proportions of each type of white blood cell, compared with only one student (3%) in the pre-resource control group. The related questions, 12 and 13, were answered correctly by 56% and 28% of the post-resource group, respectively, in comparison with 28% and 17% in the pre-resource control group. The combined scores for Questions 12 and 13 were compared for the pre- and post-resource group, and a significant improvement was found (Mann–Whitney U-test, $U = 240.500, p < 0.05$).

**Student has knowledge of the main functions of the different white blood cells in the body**

The percentage of students who answered ‘yes’ to knowing the functions of the different types of white blood cell increased from 28% prior to use of the resource to 48% after using the resource. A Mann–Whitney U-test showed that this difference was insignificant (Mann–Whitney U-test, $U = 288.500, p > 0.10$).

**Student can relate anomalies in the differential count to a broad diagnosis of possible diseases or malfunctions**

Questions 15–18 are related to this ILO, requiring students to associate a type of infection with a relevant cell type. The percentage of correct responses is increased in Questions 15, 16 and 18 but reduced in Question 17. The pre- and post-resource scores (out of 4) for these questions combined were found to be significantly different (Mann–Whitney U-test, $U = 173.000, p < 0.01$), with a significant improvement in the score for the post-resource group.

**Functionality of resource**

Questions were included at the end of the post-resource assessment for evaluative purpose. The majority of feedback was very positive. 96% of participants rated the resource as either useful or very useful, while 84% thought that it was either effective or very effective in improving their knowledge of white blood cells (shown in Fig. 6). All participants found the resource either easy to use or very easy to use and 92% rated as either enjoyable or very enjoyable as illustrated in Fig. 7. Fifty-two per cent of students thought the resource was challenging, while the remainder rated the level of difficulty as ‘just right’.
Table 1. Responses to open questions requiring comments and suggestions from participants

<table>
<thead>
<tr>
<th>Header themes</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful/enjoyable/informative</td>
<td>11</td>
</tr>
<tr>
<td>Enjoyed case study/patient scenarios</td>
<td>4</td>
</tr>
<tr>
<td>Enjoyed repetition</td>
<td>3</td>
</tr>
<tr>
<td>Easy to use/user-friendly/easy layout/ easy to understand</td>
<td>5</td>
</tr>
<tr>
<td>More information needed</td>
<td>1</td>
</tr>
<tr>
<td>Too much information/too complicated</td>
<td>2</td>
</tr>
<tr>
<td>Enjoyed games</td>
<td>4</td>
</tr>
<tr>
<td>No comment made</td>
<td>7</td>
</tr>
<tr>
<td>Would like summary slide after each section/more questions after sections</td>
<td>2</td>
</tr>
</tbody>
</table>

Further comments and responses to open questions

The post-resource evaluation questionnaire included new questions which gave the participants an opportunity to make comments about the resource. Similar words/phrases were grouped together in order to handle the responses to these open questions, while care was taken in order to prevent the introduction of bias in this procedure. Header themes identified and number or responses are shown in Table 1. Students enjoyed the presentation of theory through scenarios (n = 4), comments included ‘I most liked the way that the resource was set up as a kind of case study and you followed the process through for each patient’ and ‘It is very user-friendly and I like how it relates theory to real examples’. They also enjoyed the repetition of information about the cells throughout the resource with comments such as ‘I liked how you kept repeating info on the cells throughout instead of just mentioning them once’. A number of participants gave positive comments on the overall resource, with several students stating that the resource was both enjoyable and informative (n = 11).

Discussion

Effectiveness of the resource

Prior to use of the resource, the target audience was shown to have very little knowledge of white blood cells and the differential count, indicated by a low median score for the pre-resource group of <30%. Participants felt they were unfamiliar with most or all types of white blood cells as indicated by responses to the open questions (see Fig. 1 for questions). The poor knowledge demonstrated by the pre-resource group illustrated the necessity of a clear but relatively basic introduction to the five types of white blood cells and the differential count. The Mann–Whitney U-test on the assessment scores from the pre- and post-resource groups revealed that there was a significant improvement in knowledge in the post-resource group and that the median score had doubled (Fig. 5). An increase in correct answers is shown in Fig. 4 for all questions apart from Questions 5 and 17. Questions 16 and 18 were the questions on which participants most improved, with an increase in correct answers by over 40% of students. These questions relate to topics that are addressed directly and explicitly within the resource. The topics are introduced individually, and are directly related to the patient scenarios and diagnosis that the participants were asked to make within the resource. This shows that the use of scenario/problem-based learning is effective in enabling the acquisition of knowledge as suggested by Rhem21 and Allen.22 A significant improvement in scores was found overall for the five questions that directly tested ILO 1, showing that it had been successfully achieved. However, as stated previously, there are a reduced number of correct responses to Question 5 in the post-resource group in comparison with the control group. Fewer students were able to recognize the monocyte after using the resource, this cell type may be regarded as more difficult to recognize than some other cell types, as found by many technologists,23 due to its varied shape and occasional misinterpretation as a lymphocyte.

Three out of the four ILOs were achieved, showing that overall the resource was a success. Although knowledge was significantly improved in the group who used the e-learning resource, for the majority of questions, the percentage of students answering correctly never exceeded 60% (seen in Fig. 4) and the median score for the post-resource assessment was ~59%. This shows that a significant improvement was made to the drastically low scores collected in the pre-resource assessment, but that the scores still have potential for improvement. This correlates with data from the evaluative questions, where 52% of participants rated the resource as challenging.

Functionality of the resource

The results indicate a positive attitude to the method of scenario-based learning which correlates with Prince’s11 conclusions. One hundred per cent of participants rated the resource as either ‘easy’ or ‘very easy’ to use showing that the design of the layout and navigation was successfully accessible and user-friendly to all participants. Approximately half the participants found the resource challenging. However, no participants rated the level of difficulty as ‘too difficult’, which suggests that the resource could be used to encourage students to enhance and increase an existing knowledge instead of maintaining the current or expected level of knowledge. The results showed the majority of participants found the resource enjoyable, indicating that the design was successful in presenting the information in an interactive manner which retains their attention. Referring to comments made in the open questions; the use of games and patient scenarios were features
that participants found especially enjoyable. This indicates that interactive features produce positive responses,\(^\text{11}\) with greater participant enjoyment. Participants may feel they are being treated more maturely, developing clinically relevant study skills vital to their work.\(^\text{24}\) Most participants thought that the resource was useful and effective in improving their knowledge of white blood cells. This positive feedback could be related to their enjoyment of the resource, which in turn encourages enthusiastic learning due to better engagement with the subject.\(^\text{10}\) Also, involving the participant by using problems or scenarios promotes the construction of knowledge.\(^\text{23}\)

Limitations and improvements
Since assessment data were obtained from two independent randomly selected groups, each group acted as a sample of the target audience representing the entire group. However, given the wide variation in educational qualifications of the target audience, the prior knowledge of the group that completed the resource could have been greater/lesser than that of the control group which completed the needs analysis. This could have confounded the ability to detect resource-induced increases in knowledge and introduces potential bias in the data. This bias could be eliminated by using the same group of students to complete the assessments before and after use of the resource.

Implications for future use
The resource is suitable for integration into an Anatomy and Physiology programme of study as a supplementary material, or alternatively as part of a haematology practical, in which a set time period is dedicated to completion of the resource. It is also suitable as a revision material. In addition to nursing students, it could also be useful for life scientists, medical and dental students. The importance of the material incorporated into the e-learning resource is illustrated by the vast array of diseases related to white blood cells diagnosed and treated by the medical, biomedical and nursing professions.\(^\text{26, 27}\) The relevance of the differential count is shown by the frequency of its utilization in a wide range of settings, as both a screening tool for health and evaluation of acute and chronic haematologic diseases.\(^\text{28}\) The introduction to both the white blood cells and the differential count in the e-learning resource provides an essential basis for understanding these concepts and methods.

Conclusion
The resource met the initial aims and ILOs by providing an interactive e-learning resource which improved knowledge of white blood cells and the differential count. This was indicated by a significant improvement in assessment scores in the post-resource group and allowed the null hypothesis to be rejected.

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Author Biography
Rosemary recently graduated from the University of Manchester with a First Class Honours degree in Biology. Throughout her degree she became interested in human health and disease, and especially immunology. She is also particularly interested in the concept of e-learning and the development of scientific learning resources. Rosemary hopes to be involved in this area in her future career.

References


