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Devising an Online Resource to Help Undergraduate Science Students Critically Evaluate Research Articles

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Abstract

Critically evaluating research papers is an important vehicle for promoting acculturation into a scientific discipline. As science students progress through their undergraduate studies, their critical abilities are expected to become heightened, and research papers are read and cited in order to support a variety of assignments, such as essays, critical reviews and presentations, progressing to shaping laboratory research projects and dissertation-writing. This article describes the process of designing a modular online resource. The resource is aimed at familiarising students with the structural conventions and argumentative devices used in research papers and supporting them in deep-reading a research paper in life sciences or chemistry. The modules employ audio- and video-recorded extracts from interviews with a key author to provide a context for the origins, motivations and processes behind the writing of a specific paper, plus scaffolded questions to encourage critical evaluation of the paper. Notable features of the project were the employment of a multi-disciplinary team of staff and research postgraduates coupled with the developmental testing of the resource by undergraduates. Lessons learnt from the project are considered, including the resource's integration within the curriculum and the challenges of writing such interactive resources for different disciplines.

Introduction

The ability to critically evaluate a scientific research paper is a key element in a student's training as a budding scientist. Such evaluation helps the student familiarise him- or herself with the knowledge, culture and practices of their chosen scientific discipline (Gillen, Vaughn and Lye 2004, Kozeracki *et al.* 2006). By critically evaluating the evidence and reasoning used in scientific papers (Yudkin 2006), this should sharpen the critical thinking that lies at the heart of applying scientific method (Ladyman 2013). By noticing the strengths and weaknesses of expression in the papers students read, it was envisaged that students would also improve their writing within the discipline (Tilstra 2001, Willmott, Clark and Harrison 2003).

This article concerns the creation of an online resource called *Evaluating Scientific Research Literature* (*ESRL*), which grew out of the perceived need for students to enhance their ability

to critically evaluate the evidence and reasoning in scientific research papers. The resource was designed specifically to enable students to better apply their understanding of research literature to a variety of assignments, and especially the writing of dissertations and longer practical research reports.

The focus of this article is on the process of designing and evaluating the online resource on its journey from conception to launch, and the lessons learnt from that process. General principles from this experience may inform how such online resources might be employed most effectively within the undergraduate curriculum in the future. The detailed findings of the student questionnaire surveys and focus groups carried out during the resource's development, along with the questionnaire responses on the resource's effectiveness in the first few months after launch, are being reported separately in a forthcoming article.

The online resource, co-developed and hosted by the University of Bath Library, was devised for three discipline areas: Biology & Biochemistry, Chemistry, and Pharmacy & Pharmacology. Substantial staff changes in the Department of Chemistry before the resource's launch influenced how the resource was promoted and integrated within the Chemistry curriculum. For this reason, the emphasis of this paper is on the two life science components – Biology & Biochemistry and Pharmacy & Pharmacology.

The context for the online resource

The University of Bath, UK, is a research-intensive university with a strong emphasis on science and technology. In two of the discipline areas within the resource's scope – Biology & Biochemistry and Chemistry – more than half of undergraduates have a year's work placement incorporated within the degree programme. Such industrial or commercial experience is a factor in Bath graduates having very high rates of employability, whether in their original degree discipline or not.

The pedagogic culture in the University of Bath's life science departments involves small-group tutorials supporting or complementing lectures, seminars, workshops and lab-based practicals, and a high degree of student autonomy is encouraged and expected. There is a strong emphasis on 'hands on' laboratory investigation with at least 4 hours a week of practicals, and considerably more during final year practical projects.

At Bath, Teaching Fellows in Biology & Biochemistry and Pharmacy (authors HC and JL), and Chemistry's Undergraduate Director of Studies, had identified a lack of structured support in helping students appraise peer-reviewed research papers. In Year 1 in Pharmacy & Pharmacology and Biology & Biochemistry, students are encouraged to read and refer to material from review papers and journal articles when writing essays. In Pharmacy & Pharmacology in Years 1 and 2, students refer to research papers as part of problem-based learning (PBL) in which individuals give short presentations within their tutorial groups. By years 3 and 4, the ability to critically evaluate research papers becomes imperative, as students supplement their interpretation of lecture material, undertake at least one extended research project with accompanying report, and finally complete a dissertation. In Biology & Biochemistry in Year 2, students are encouraged to read research articles to support lecture material and in tutorials they explore research articles in some depth. In Year 3 they are expected to find and use research articles in composing essays, making presentations and for the final year project write up.

Student evaluations after completing final year projects and dissertations in Pharmacy in years 3 and 4, highlighted them feeling poorly prepared for evaluating laboratory-based research literature. In Biochemistry and Chemistry, teaching staff identified that those students who had not been on work placement were at greater risk of failing to develop effective critical skills when evaluating primary research literature. They had not been exposed to the same opportunities to write extended reports, drawing upon research literature, as those on work placement.

In response to the perceived shortcomings in developing students' critical evaluation of research papers, and given that Bath's undergraduate numbers in Biology & Biochemistry, Pharmacy & Pharmacology and Chemistry are large (approx. 120–200 each year, depending on discipline), JL proposed the development of an online resource. The resource would be usable by students whether learning independently or under staff supervision, with such flexibility being a key strength of an online resource (Collis and Moonen 2002). The resource would be interactive, designed as far as possible to promote deep learning (Biggs 1987, Marton and Säljö 1976) and self-paced to accommodate students with a diverse range of prior knowledge and experience. In order to devise the most appropriate learning resource, a multidisciplinary project team was gathered, which included three staff subject specialists (one from each discipline area), a writer/educational developer and an online instructional designer. It was proposed that research postgraduates would be involved in developing the resource, which would be tested by undergraduates and refined before launch.

The project team and the nature of the resource

The resource was to be developed from scratch to a tested and launched final product within 10 months. The three subject specialists had responsibility for choosing an appropriate paper in their respective disciplines and in each case enlisting one of the paper's key authors to be interviewed about the paper. At least two research postgraduates in that discipline were also recruited to read and comment on the paper, and to devise suitable questions and answers about the paper to be used as raw material to incorporate in the resource. Two of the subject specialists, JL as project leader and HC as deputy leader, had primary responsibility for devising the regime for testing the resource during its development. This involved recruiting undergraduate students in the three disciplines to each work through one of the resource's four modules and to report back by completing pre- and post-test questionnaires and attending focus groups.

Two of the team members (TD and TR) had considerable previous experience in developing online resources at Bath. The new resource was an opportunity to draw upon the university's leading edge practice in using Articulate e-learning software (http://www.articulate.com/). The resource would incorporate a high degree of interactivity as part of the student experience, employing a wide variety of automated quizzes with tailored feedback. The resource incorporates audio and video extracts from interviews with paper authors, with opportunities for students to read and interact with research papers, through reflection and guided questioning. It contains several features considered to be sound practice in online resource design including: discipline-oriented, clearly stated learning objectives (outcomes); automated feedback to quiz answers; and differentiated content to cater for learners of differing ability and previous experience (Somoza-Fernández and Abadal 2009, Tancheva 2003).

The intention was to make the resource engaging and worthwhile for undergraduates by focusing on research papers published by University of Bath staff and relevant to students on their specific disciplinary programme. Interviewing a key author for each paper would provide insight into how the research paper, and the work on which it was based, came about. This would 'breathe life' into using the paper as a focus. Forging a strong link between teaching and research serves many purposes, including: reinforcing the conception of knowledge as an outcome of evidence-based enquiry; promoting the expertise of researchers within the department; creating opportunities for undergraduates to engage in laboratory work of direct relevance to 'real-life' research; and offering insight into local research to which students might further contribute should they wish to stay on as postgraduates (Jenkins *et al.* 2003, Sears and Wood 2005).

Evaluating Scientific Research Literature (*ESRL*) evolved to become a four-module resource comprising a broadly science-focused introductory module and three subject-specialist modules – one each for Biology & Biochemistry, Chemistry, and Pharmacy (Fig. 1). Each module provided at least one hour of interactivity, with optional extension activities for the subject-specific modules offering at least a further 45 minutes of interactivity. The introductory

module was aimed primarily at Year 1 and 2 students, with the subject-specific modules catering for Year 2 and above.

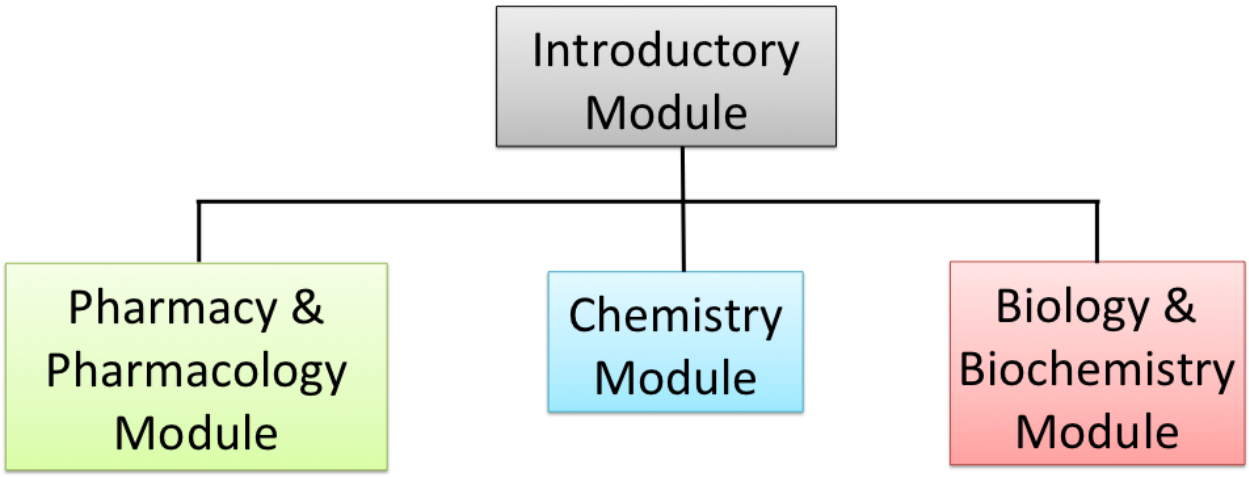

Figure 1. Overview of the Evaluating Scientific Research Literature (ESRL) online resource

ESRL was hosted on the University's virtual learning platform Moodle 2.5 (https://moodle.org/). *ESRL*'s focus on reading and critical evaluation complemented an existing more generic six-module *Academic Writing Skills* (*AWS*) online resource created at Bath, which addressed essay composition, practical report writing, argumentation, critical appraisal of source material, and referencing and plagiarism (Day, Humphreys and Duncombe 2010). By including members of the same team who had developed *AWS*, tight integration between *ESRL* and the previous resource could be ensured.

The introductory module of *ESRL* was designed to offer students an overview of the context for scientific literature in general, and peer-reviewed, laboratory-based research papers in particular. It offers responses to key questions: Why are such papers written and read? By whom and how? How are such papers structured? And what are useful strategies for reading them? The intended learning outcomes for students using the introductory module were framed as enabling them to be better able to:

- explain the motivations of researchers in writing primary literature;
- justify the value of reading research articles for students, researchers and practitioners;
- explain the structure and function of each part of a research paper;
- quickly view a research paper to decide whether it is worth reading further for a particular purpose; and
- write their own scientific reports of practical investigations.

The three subject-specific modules each adopted a broadly similar format, but differed in content and design depending on the paper's research focus, discipline specific conventions and the pedagogic preferences of the staff member from each discipline. Each subject-specific module began with an explanation of the importance of critical evaluation (and its meaning in the context of that discipline), what critical evaluation involves more generally (which was explained in relation to the higher-order skills: analysis, synthesis and application) and specifically in relation to the research papers in that discipline. This followed with a justification for reading that paper in terms of the student's educational development. For example, the chosen paper for the Biology & Biochemistry module, Al-Adsani *et al.* (2010), concerned cellular reprogramming, an important research strand in cancer treatment and regenerative medicine. The cell biology techniques reported in the paper are core to many mammalian studies relating to medical research, and some of these methods might be used by students during their work placement or in their final year projects.

The module then offered both a research and writing perspective for the chosen paper. This part of the module was aimed at giving each paper a real-life context, revealing the paper was written in response to certain demands and several researchers (in all cases in geographically very disparate locations) collaborated to carry out the research and then write the paper, and the processes by which they did so.

After the introduction to critical evaluation and the paper's research and writing context, the rest of the module took the student, step-by step, through each part of the paper – title, abstract, introduction, and so on, through to references – picking out key learning points and employing numerous quizzes, which encouraged the student to engage deeply with the text and gave feedback on progress. 'Tip' buttons opened up boxes onscreen to provide additional background information, enabling the resource to be used flexibly by students with different levels of expertise. A wide variety of quiz designs were used, including mix and match (Fig. 2), multiple-choice (Fig. 3) and pull-down menu (Fig. 4). Such closed response quizzes confirmed correct or incorrect answers and supplied explanatory guidance (Fig. 5). However, to foster deeper thinking (Dewald *et al.* 2000) some open questions were employed, which required written answers. In such cases, sample 'model answers' were provided.

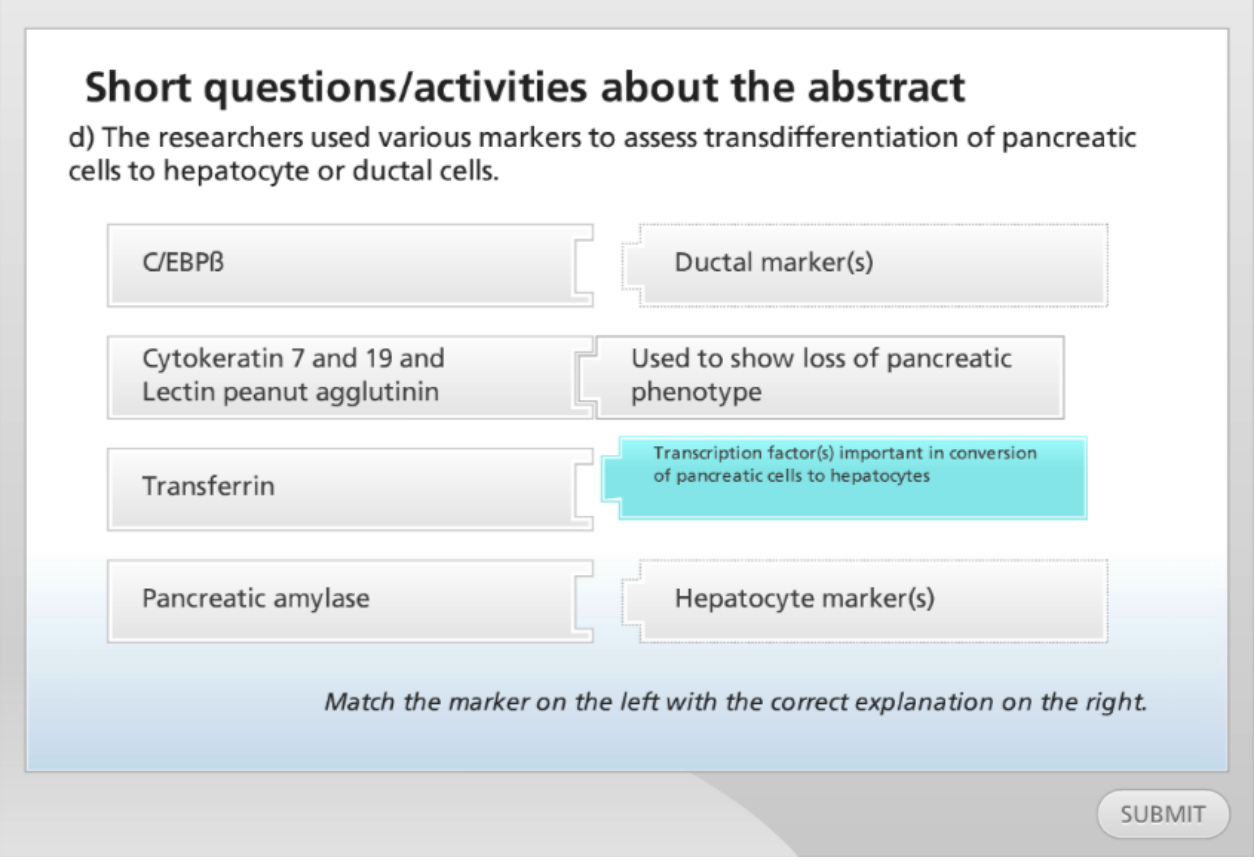

Figure 2. A mix and match question from the Abstract section of the Biology & Biochemistry module. One item on the right has been selected and matched with a chosen partner on the left. Another item (highlighted) is in the process of being dragged to a selected partner.

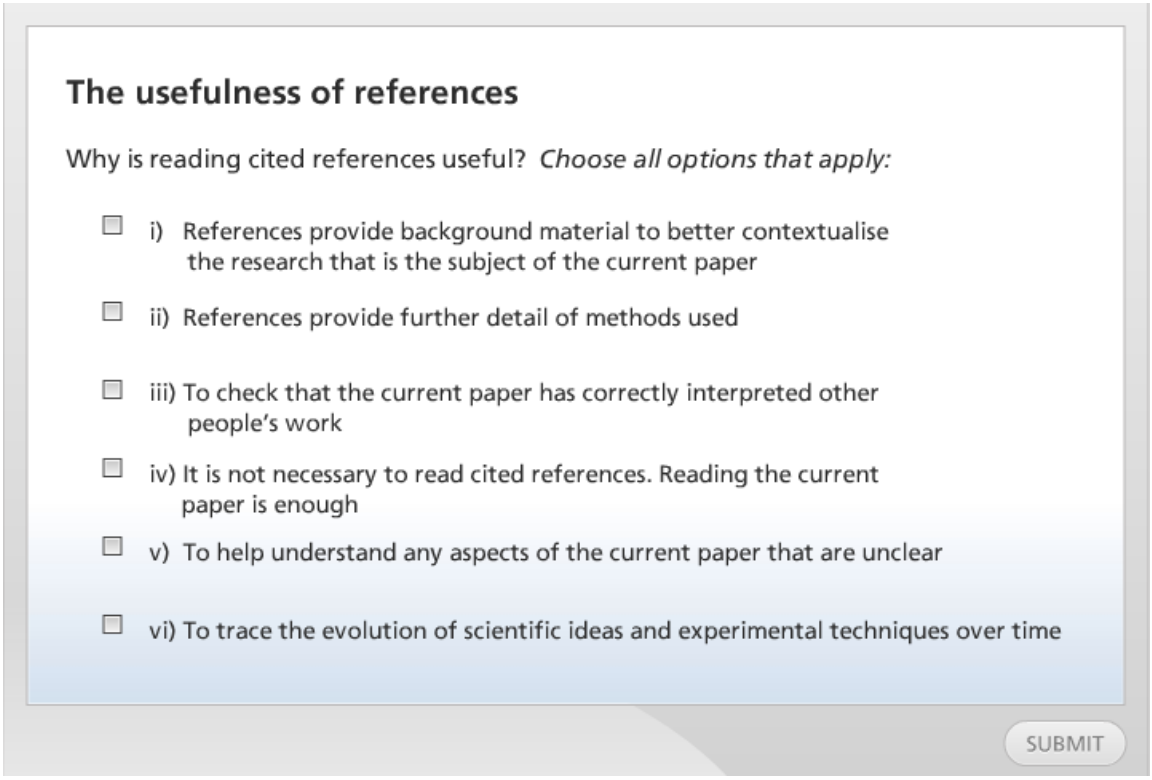

Figure 3. A multiple-choice question from the References section of the Biology & Biochemistry module. For a correct answer, a student would select all options except iv).

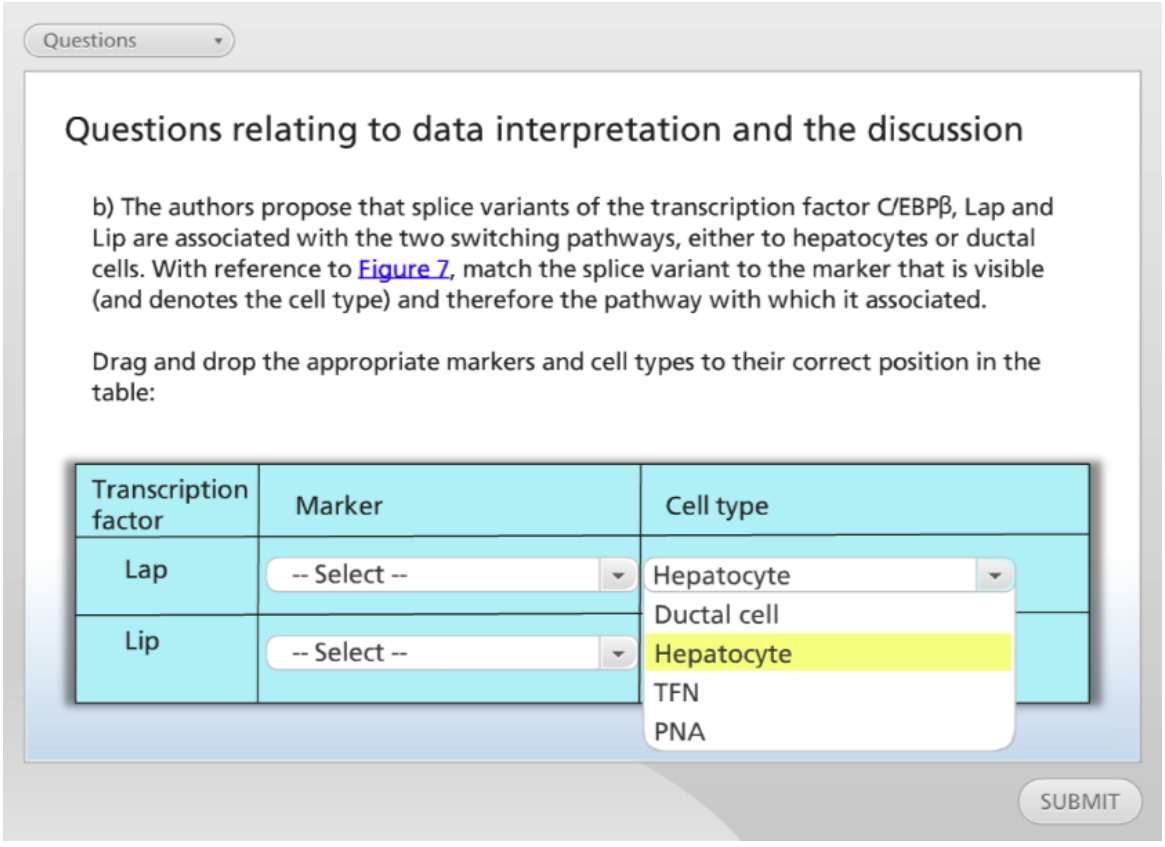

Figure 4. A pull-down menu question. In practice, many such questions incorporated images from the relevant research paper. In this example, the student can follow a hyperlink to the relevant figure.

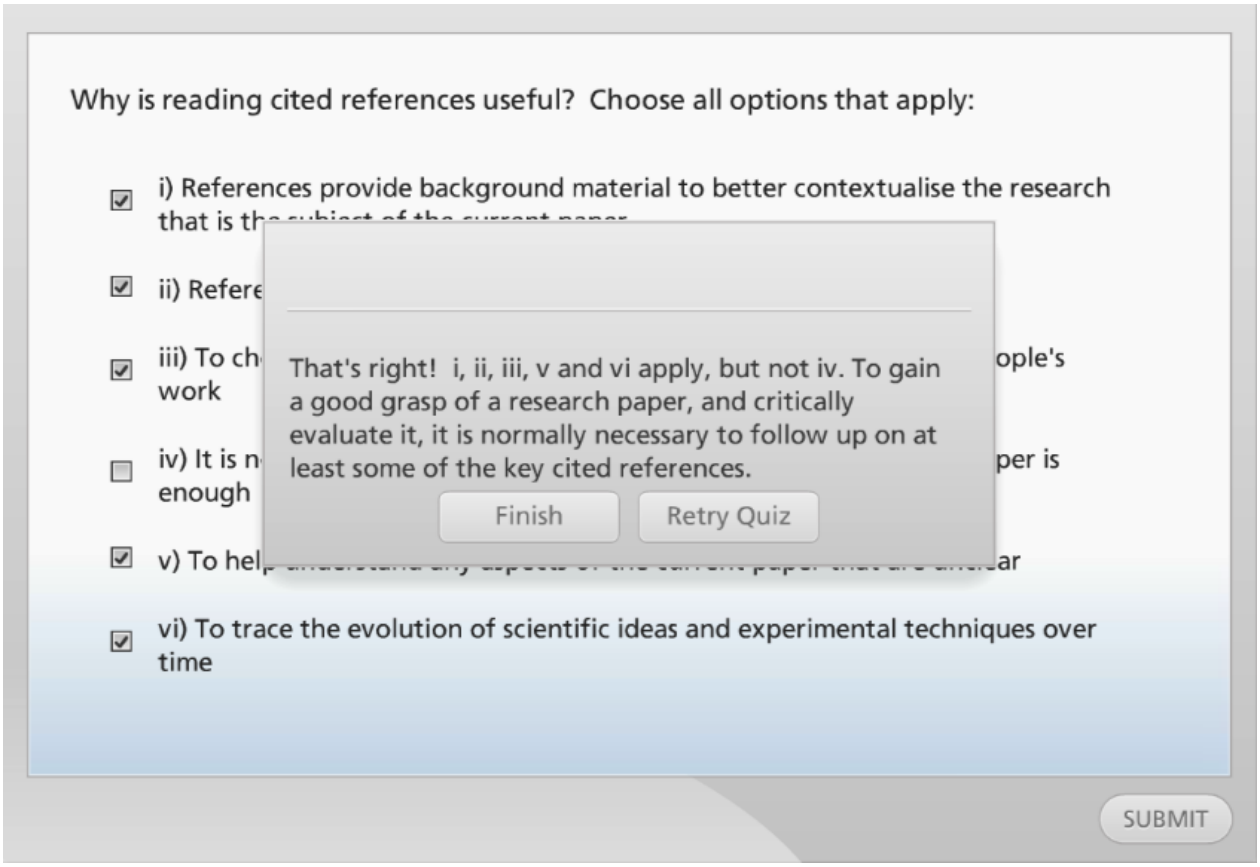

Figure 5. An example of feedback given in response to a correctly answered question.

Working through the paper, questions were carefully scaffolded, from simpler to more challenging, with the optional extension activity having the most challenging elements and appropriate for more advanced undergraduates. One of the key design challenges was in finding ways for students to read relevant parts of the research paper onscreen, while answering onscreen questions. This was achieved in two ways: by having parts of the paper embedded within the quiz elements, and encouraging the student to download a portable document format (pdf) copy of the entire paper to which they could refer.

The intended learning outcomes for students using a subject-specific module, building on those of the introductory module, were framed as becoming better able to:

- justify the value of reading research articles for students, researchers and practitioners;
- explain the function of each part of a research paper;
- locate and interpret particular details of the methods and results;
- identify the kinds of questions appropriate to ask in evaluating other research articles; and
- apply aspects of writing style, structure and argumentation to their own scientific reports of practical investigations.

In addition, through deep reading of a paper and engaging with the contextual commentary included in the introductory and subject-specific modules, we expected students to become more aware of:

- the motivations of researchers in carrying out such research;
- the complementary relationship between text and figures within a paper; and
- the potential impact on researchers, practitioners, policymakers or the general public, of the research reported in a paper.

A recent review article (du Prel, Röhrig and Blettner 2009) and books (Langton 2013, Yudkin 2006) aim to assist students, researchers and disciplinary practitioners in gaining an appreciation of experimental techniques – their rationale, strengths, weaknesses and limitations – so that the reader can critically evaluate published research more effectively. However, unless a student has direct practical experience of relevant laboratory techniques it is difficult for him/her to put him/herself in the position of a researcher and so evaluate and critique the methods, results, discussion and conclusions presented in a research paper. As Yudkin (2006: 51) contends 'you cannot judge results without judging methods'. Thus, in order to judge the validity of methods used, there may be a requirement for students to participate in relevant laboratory experience (or at least, have guidance from someone with that experience).

Before students can reach heightened critical awareness of methods and results, they need to become familiar with the structures and argumentative conventions of research papers in their discipline, and the research landscape in which papers are written and published. The design of the *Evaluating Scientific Research Literature* online resource is predicated on building this awareness, first through a more generic introductory module with reinforcement in a discipline-specific module focusing on a specific research paper.

The development team wished the modules to be used flexibly by students, perhaps in the presence of a teacher in a structured session but also by the students on their own, as and when the need arose. The earlier Bath online resource, *Academic Writing Skills* (Day, Humphreys and Duncombe 2010), is used in this manner. A major strength of such resources is that they are used by students at the point of need, when they wish to apply their knowledge, rather than a timetabled element within the curriculum that might be disconnected from application.

Developing the resource

Through several briefing and discussion sessions, in which all project members contributed, the resource author (TD) accepted the design brief and developed the introductory module structure and content. He chose the scientific research paper Sneddon (2003) as a model on which to hang the structure of much of the introductory module. Sneddon is readily comprehensible by students from a wide variety of science disciplines. The paper's sections and argumentation are coherent and easy to follow, but sufficiently idiosyncratic to make the paper interesting to read. In addition its theme – 'do fish feel pain?' – is likely to be of interest to a wide audience.

To help engage students' interest at the beginning of the introductory module, users could click on audiotape clips of students explaining why and how they had needed to refer to the primary scientific literature during their course. Audio or video clips from leading academics involved in the project explained the importance of reading primary literature, how it has shaped their research and the challenges for undergraduates encountering such literature.

TD interviewed a key author for each of the three chosen subject-specialist papers (Table 1), to record advice on good practice for the introductory module and offer breadth and depth for the context for each research paper (see Appendix 1 for the schedule for the semi-structured interview). Meanwhile, the subject specialists recruited at least two postgraduates to review each paper in order to interpret and summarise key learning points and to devise potential questions and answers as a bank of material to draw upon when devising the resource (see Appendix 2 for schedule). From here onwards, the online instructional designer (TR) played a major role, working closely with TD to transform text, instructions and audio- and videofile extracts into visually engaging, comprehensible onscreen elements (Figs. 2–5).

Table 1. The papers and authors chosen for the three subject-specific modules

Module	Biology & Biochemistry	Pharmacy & Pharmacology	Chemistry
Paper	Al-Ahmadi *et al.* (2010)	Drew *et al.* (2011)	Thomas *et al.* (2012)
Interviewee	Senior doctoral researcher	Lecturer / laboratory leader	Professor
Discipline/ subdiscipline	Biology/ cellular trans-differentiation	Pharmacy/pharmacology /neuroscience	Chemistry/crystallography
Nature of the research finding	Worthy research, consolidating earlier work, but concerning a model with currently limited popularity.	A tested hypothesis is refuted. Advancement in structural knowledge concerning the mouse brain.	Characterisation of a novel chemical species with potential for application in hydrogen storage, leading to a further key paper.
Background	Continuing a strand of research dating back more than a decade.	Continuing a strand of research dating back to 2005/6.	A serendipitous finding, and a new line of enquiry for the research group (with potentially high impact).
Methods/ approaches	Trans-differentiation, gene expression, cell culture, immunoflurorescent staining, immuno histochemistry, specific molecular biology techniques, electron microscopy	Drug treatment, immunohistochemistry, microscopy, stereological analysis	Crystallography, X ray analysis, neutron data capture, plus numerous associated analytical techniques.

Through further meetings and drawing upon the material provided by postgraduates, the subject-specific modules took shape. Through an iterative process extending over some 12–16 weeks, module components co-developed by the main author and the instructional designer were then reviewed by the subject specialists and revised. Acquiring the expertise to read and evaluate scientific research literature is developed over time through knowledge construction, practice, reflection and discussion – an on-going process for each individual. To facilitate the first three of these four elements, the online content had to have appropriate depth to be challenging, offer self-assessment to check knowledge, prompt reflection, and be sufficiently engaging and interactive to sustain interest.

Testing the resource in development

When the online resource was at an advanced stage, some 18 weeks before launch, undergraduate students in the three subject disciplines were employed to test the resource and give feedback on its design and best use. Paying students to participate is common practice in testing the design of online resources, and clearance on this procedure was obtained from the university's department with the remit for quality control and academic integrity. The students were regarded as 'independent agents', recruited to improve the quality of the resource. None were taught or assessed by project members, and it was explained that their involvement in testing would not detrimentally impact their academic progress. In conducting the surveys and focus groups, and reporting findings, many BERA (British Educational Research Association) ethical guidelines were followed. Students gave informed consent, they were ensured anonymity, their data were kept secure, there was no coercion to participate, and they could opt out at any stage. Thirty one students were recruited by JL and HC: eight from Biology & Biochemistry, 16 from Pharmacy & Pharmacology and six from Chemistry. Students were given two hours to test one of the resource modules under the guidance of JL and HD. Fourteen students tested the introductory module, and 16 students were assigned to one of the subject-specific modules.

Before testing a module each student completed and returned a pre-test questionnaire to ascertain the participant's previous experience. During testing they were encouraged to write notes, detailing any software, navigation or comprehension problems they encountered.

Immediately after using the resource, students completed a post-pilot questionnaire in which they reported on the quality of their learning experience and the usability of the resource. Finally, later the same day, each student joined one of four focus groups (scheduled according to timetabling availability) to gather students' opinions and reported experiences in greater depth. The focus groups explored the students' experience of finding and reading research articles, what the students liked and did not like about the resource, and how the resource could best be used, whether integrated within curriculum activities or completed independently by the student.

Data from the post-test questionnaires were analysed by two of the project members (HC and JL) for emerging themes in the two categories: resource design and learning experience. In the analysis, students' learning experience was related to the student's discipline and level of expertise as reported in the pre-pilot questionnaire and based on year of undergraduate study. Focus group audio-recordings were transcribed by employed postgraduate students and then analysed by HC and JL for emerging themes under three main headings relating to section headings in the questionnaire: student approaches to reading research articles; student opinions on the online resource's design; and their views on how students might best engage with the resource within the curriculum.

All those using the introductory module and 15 of 16 (94%) completing a subject-specific module, reported the resource as being easy to learn from. All completing the introductory module and 14 of 16 (88%) using a subject-specific module would recommend the resource to a fellow student. Students testing the introductory module reported their skills had improved in 5 of 7 areas. The largest improvements were seen in their understanding of what is included in the different sections of a research article and feeling better prepared and more confident to read one. In addition, students testing the subject-specific modules expressed a better understanding of the term 'critical evaluation' and the importance of data presentation, especially amongst Chemistry and Pharmacy & Pharmacology students respectively.

These largely positive findings agreed with responses emerging from focus groups. Students testing the introductory module claimed they learnt especially about the importance of scientific publication, the different types of scientific literature and how to select the best articles. They also gained a greater understanding of the structure of journal articles, the purposes of the different sections and how to read them.

Students testing the subject-specific modules reported learning more about how to evaluate a journal article and how to use it for different purposes. A heartening response was that many students claimed that completing the modules would help them write laboratory reports, which in many cases follow the structure and conventions of research papers. A key learning outcome for the resource, for students to recognise the close linkage between text and visuals in papers and apply this in their own laboratory reports, was highlighted in many students' responses.

Reflections on lessons learnt

Following the launch of the resource, the project team has reflected on the experience and offers some generalisations and key lessons learnt below.

1. Choosing suitable journal articles for the resource

The project team's collective experience suggests that the chosen article needs to complement the existing curriculum rather than be a 'bolt on', marginally relevant item. Providing the chosen article is interesting, the more embedded it is in the existing curriculum, the better. The more justification there is for a student to access the resource, the better.

The use of a locally-authored paper in an online resource requires 'buy in' from a key author. The development team discovered, given the dynamics of research teams and personalities involved, such 'buy in' was not always obtainable. For example, a senior author might have a

strong research orientation and may not wish to be involved in developing a teaching/learning resource. Even if interested, a key author might be reluctant to be interviewed and audio- or videotaped and feature in an online resource. Such considerations may influence the paper finally selected.

Choosing suitable articles for the online resource revealed some of the challenges inherent in reading a research paper that the resource was, in fact, designed to help mitigate. A superficial reading of the paper (even by a subject specialist) may not reveal the particular strengths and weaknesses of a paper to be used for the chosen purpose in an online resource. In fact, it was often only when a postgraduate student, with in-depth knowledge of the topic area became involved, that the true suitability of the paper as a resource for students was revealed.

The online accessibility of an article by students could be a key factor to consider. Initially, journal articles were chosen for their fit with curriculum relevance, local authorship and perceived pedagogic suitability. When the project began, the focus was upon delivering an internal online resource. As the project progressed, the possibility grew of developing it as an open educational resource (OER). Permissions were given by authors for extracts from their interviews to be included in an OER. However, negotiating with publishers the open-access use of normally subscription- or purchase-only articles can be a protracted business. It may be more appropriate to choose open-access articles at the outset, providing they meet the other key criteria.

2. Disciplinary differences

During the project, team members were approached by other resource developers at Bath. They wished for the *ESRL* to be adapted for research postgraduates, or for it to be modified for undergraduates in other disciplines. Doing so was not feasible given the time constraints and budget for the project. These approaches from staff revealed a variety of misconceptions about the resource. In particular, to what extent could guidance in the introductory module be applicable to other disciplines? With a larger budget, and more time, it would be feasible to develop a resource applicable for a wider range of disciplines encompassing all or most STEMM (science, technology, engineering, maths and medical) disciplines. To do so would require engagement with at least one specialist representing each contributing discipline.

STEMM disciplines, like other academic disciplines, have their own methodologies and epistemologies – the methods, assumptions and distinctions by which the community of practitioners generate knowledge (Pace and Middendorf 2004). Across STEMM disciplines, such conventions differ in detail, which ultimately becomes reflected in the structure, viewpoint and narrative style of the discipline's published peer-reviewed papers. For example, across the three *ESRL* disciplines, the length of chosen papers differed markedly, from about 4,500 words in the Pharmacy & Pharmacology paper to about 3,000 words in Chemistry – reflecting different reporting conventions for these disciplines. The use of viewpoint – personal or impersonal – varies with discipline. In argumentation in mathematics papers, for example, 'we' and 'our' often refers to the wider community of practitioners. When 'we' and 'our' are employed in peer-reviewed journal papers in the *ESRL* disciplines, it is usually sparingly, confined to introductions, discussions and conclusions, and most often refers to the paper's authors. Such examples highlight the dangers in taking the attributes of a few papers in a restricted range of disciplines and assuming that these apply to a wide range of fields.

3. Resource design

The instructional designer, in translating the pedagogic intentions of the rest of the team, drew upon Laurillard's (1993, 2002) conversational model for design in educational technology. In effect, the resource had to offer appropriate mediation between the narrative being presented by the original authors and the resource-development team and its interpretation by the reader. The resource is performing the function of mitigating for the absence of the in-the-

moment presence of the human facilitator found in conventional tutorial, seminar or lecture settings. In so doing it needs to provide appropriate feedback to the user, to steer them in constructive directions, through appropriate responses to user's actions.

In designing a complex, interactive resource, numerous design elements need to be considered and selected, among them: screen layout; colour conventions; interactive cues; displaying highly readable text and images in a contextual, meaningful array; strategies for seamless navigation between information, activities and quizzes; and methods for providing feedback. Articulate Studio 09 was the instructional design software chosen given its sophistication and flexibility in blending text and images, and in the wide range of quiz and feedback styles it supports.

As with any other e-learning resource, its sustainability needed to be considered, both in terms of revising and refining content and design, and ongoing technical support. In our experience, such considerations are not that expensive, in comparison to the original set up costs, but are rarely given the attention they deserve. For this project, ongoing technical support is provided by the University Library. A considerable archive of project-relevant material is maintained by the Library and the project leader, including a wiki tracking all major decisions and landmarks in the evolution of the resource. Nevertheless, an injection of further funds would be necessary if the resource were to be radically expanded, and a multi-disciplinary team, such as the one originally brought together, would be a key element in shaping that expansion.

4. Linkage to the curriculum

Where the resource might best fit into the curriculum was a key discussion point in the student focus groups. Whilst students were positive about using the resource they were also realistic about their motivation to seek out and use study skills resources in their own time. Students considered the problem with much study skills training is that it is offered at the start of the year but they have then forgotten the relevant content, or mislaid how to access it, when they need to do so later. Students felt the resource would be most effective if it were offered and promoted to them at the point of need. Timetabling a session to complete one or more modules at such a time was considered to be another viable strategy. Questionnaire and focus group responses were in accord with current advice that e-learning provision is best integrated into the curriculum and its use – whether in or out of class – promoted at the point of need (Ruiz, Mintzer and Leipzig 2006).

The point at which the students thought the resource would be most useful varied not only with department, but even with undergraduate degree programme within a department. Biochemists would find the introductory module useful early in the first year, whereas Biologists and Pharmacists & Pharmacologists would prefer to use it later in the first year, or during the second year. The Chemists are not required to interact much with research articles, or to write extended reports, until the third year.

The four-module ESRL resource was conceived with a life sciences or chemistry student first undertaking the introductory module and later their particular subject-specific module. As with the introductory modules, there were disciplinary differences as to when students regarded uptake of the subject-specific module to be most appropriate. In Biology & Biochemistry and Pharmacy & Pharmacology, students favoured completing the subject-specific module at the same time as paper-relevant topics were being studied in Year 2. In Chemistry, students favoured its use more flexibly across Years 2 and 3. Students, irrespective of discipline, unanimously agreed that the resource was best used formatively for skill development, as originally conceived, rather than being adapted for summative assessment. Timetabled time for using the resource, and incorporating pass/fail criteria for its use within a unit, were student suggestions for helping ensure high take up.

Returning to the source: what does it mean to read and understand a paper?

The reading of a research paper is usually matched to a specific purpose – whether predominantly educational or predominantly research-orientated – and therefore the precise reading strategy is likely to differ in each case (see, for example, Day 2013: 66–80). For example, an undergraduate student reading a paper for background information for an essay in their first year is likely to concentrate on the paper's abstract, introduction and conclusions, and perhaps discussion, only occasionally closely scrutinising the method and results sections. That same student, in their final year, devising a research protocol for a practical investigation, might ultimately pay more attention to the method section than any other. There is no single 'good' way to read a paper. The *Evaluating Scientific Research Literature* resource sought to embrace this diversity, encouraging students to be purposeful, inquisitive and critical in their reading of scientific papers at different stages in their undergraduate progression.

Reading scientific research papers is no easy task (Knight 2003). While a well-intentioned online resource (Raff 2013) suggests strategies for non-scientists in reading scientific papers, scientific journal articles – certainly in the three discipline areas for the *ESRL* resource – have become highly specialised and increasingly impenetrable. Even experts in the field will not understand every research paper they read. As Professor of Chemistry, Chick Wilson, commented for the *ESRL* resource:

> 'The one thing I would say to students encountering the [primary] scientific literature for the first time is to try not to pretend to yourself that you've read and [fully] understood a paper. … As an experienced academic there are a significant number of papers that I read that I reflect back on and say "I didn't really understand that".'

It is well to develop students' capacity and confidence in reading scientific papers critically, but this needs to be tempered with realism if not humility.

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Appendix 1. The schedule for the semi-structured interview with a paper author

1. Why was this journal chosen for the paper?
2. What was your contribution to the paper and the research it reports?
3. Who else contributed, and how?
4. How did the research on which this paper is based come about? Is this typical for the work in which you are involved?
5. Is there anything unusual about the research, or the paper itself, or the processes involved?
6. How does this paper sit in relationship to papers you have published before and those you intend to publish after?
7. How was the paper written? Was the publishing process smooth?
8. How happy are you about the paper? What were you most proud of? If there is anything about it you would wish to change, what would that be?
9. How do you think this paper could best be used as a learning resource for undergraduates?
10. Anything else you wish to add?

Appendix 2. The schedule (abridged) used by postgraduate students reviewing a paper for a subject-specific module, and responding with observations, key learning points, and potential questions and answers for use with undergraduate students

Instructions to postgraduate students

- Answer generic questions below. If you don't know the answer, give your opinion/point of view.
- Write and answer 1-3 article-specific questions for each section of the journal article.
- Base questions around what students would need to know in order to understand the paper.
- Include statements as to how they could use different sections for different purposes.
- Try to provide insight as to whether there was anything special or unusual about the paper.

NOTE: this resource is initially aimed at Year 2 undergraduates. Please make questions and answers accessible for such students.

1. General information about the article

- Examine the general information on the first page of the article's pdf: e.g. Publisher, Journal name, Volume number, Year, Page numbers, any article history).
- What can you learn from this information? Is the article open access? What is its impact factor? How current is it?
- How might such information be useful?
-

2. Title:

- Is this article descriptive, comparative or analytical? How do you know this?
- Write 1-3 article-specific questions to help students understand what the paper is about. This might include explanation of vocabulary.

3. Authors:

- Who are the most important authors?
- Who is the likely group leader?
- How can you use this information to learn about the reputation of the group?
- Who is the corresponding author? Why is this useful to know?
- Where was the study performed? Why is this useful to know?

4. Abstract:

- What is the purpose of the abstract?
- How is it structured?
- Which sentence(s) provide(s) a background to the study?
- What was the research question?
- Is there any mention of the method(ology) used?
- What were the main findings?
- What is the significance of the findings?
- Please write 1-3 additional article-specific questions to guide students through the content and help them understand what the paper is about.
- Explain how, as a researcher or a student, you could use information from the abstract.

5. Introduction:

- What is the purpose of the introduction?
- How is it structured?

- Which sentence(s) provide(s) a background to the study?
- How exactly do the cited references contribute to the background?
- Which sentence defines the research question?
- What is the rationale for the study?
- Write up to 3 article-specific questions to guide students through the content – the answers should provide students with the information they need to understand the introduction.
- Explain how, as a researcher or a student, you could use the information from the introduction.

6. Materials and Methods (or its equivalent):

- What is the purpose of this section?
- How is it structured?
- How do cited references contribute to the purpose and structure?
- Write up to 3 article-specific questions to guide students through the content – the answers should provide students with the information they need to understand the methods. Answers to some questions might explain vocabulary. They could also allude to any specialised techniques, the purpose of controls (if mentioned) and any limitations, if known.
- Explain how, as a researcher or a student, you could use information from the materials and method section.

7. Results (sometimes combined with discussion):

- What is the purpose of the results section?
- How is it structured?
- How is the data presented? Why is the format of any data presentation appropriate?
- Where is the data from controls? What does this show?
- What is the purpose of the figure legend?
- If there is any statistical analysis, explain its importance.
- What is the purpose of the narrative text in the results section?
- Do the authors take multiple approaches to answering the same question? If so, why is this important?
- Write up to 3 article-specific questions to guide students through the content and help them understand what the data mean.
- Explain how, as a researcher or a student, you could use information from the results section.

8. Discussion & conclusion:

- What is the purpose of the discussion section?
- How is it structured?
- Does the authors' interpretation agree with the data presented?
- Are there other possible interpretations?
- What were the limitations?
- What comparisons are made with other studies?
- What are the main conclusions?
- What is the significance of these findings?
- Are there any suggestions for further study?
- Write up to 3 article-specific questions to guide students through the content and help them understand what the data mean.
- Explain how, as a researcher or a student, you could use information from the discussion and conclusion section.

9. References:

- What is the purpose of the references section?
- Which types of publication are cited? Does this matter?

- Does the article's reference list contain a wide survey of existing literature?
- Is the list current? Why is this important?
- Does the research group cite their previous work?
- Explain how, as a researcher or a student, you could use information from the references section.