

Creating effective teaching materials – the C21 project

1. Introduction

The C21 project is a collaborative effort involving professors, graduate and undergraduate students in physics and physics education at the University of British Columbia. The aim of the project is to create a website that provides examples and resources to help high school and undergraduate teachers include real-world contexts in their teaching of physics.

Why real world?

The concepts and thought processes used by physicists arise due to an effort to understand the world around us and the way we teach physics should reflect this to properly convey what physics is and why it is worth learning. Several studies have shown that typically by the end of their first term in university physics, students see physics as less useful and relevant to their lives [1],[2]. Student interest increases, however, when there is connection to the real world [2] and plays an important role in student achievement [3].

What is real world?

The real world is complex, it is not justly encapsulated by any one branch of science. For this reason C21 takes an interdisciplinary approach to physics combining the physics concepts with the contexts and subjects where they are most useful or interesting. Three main topics currently on the website are 1) energy and the environment, 2) biology and medicine and 3) skills and techniques. These topics were chosen specifically because of their richness in applied physics concepts, relevance to our society, ability to provoke interest among a general audience, and need for resources.

How can we effectively create teaching materials based on real world contexts?

When considering possible criteria for effective teaching materials, the first question that comes to mind is effective at what? Teaching materials can serve a variety of purposes such as teaching concepts, skills or attitudes. Whatever the intended purposes are they should be clear and every element contributing towards those goals [4]. One of the fundamental principles of designing effective teaching materials is not to include what is distracting or extraneous to useful teaching purposes. Putting the material in a real world context is an important way of making teaching materials more effective though certainly it is not a cure all by itself. If the teaching material involves learning vast amounts of interesting though irrelevant information then that would only detract from student learning adding to cognitive overload [5]. The articles created for C21 aim to teach physics concepts primarily using the real world context as an aid not a distraction.

Another question of importance is what impression are we trying to give our students about the subject as a whole? Being able to apply formulas and algebraically manipulate expressions is not an unworthy skill but it is not the only skill we want students to feel that studying physics involves. Teaching materials should be designed considering the concepts and thought processes that the students should gain, not necessarily for equations they are to memorize.

This paper will present the design of the articles on the site with reference to the pedagogical principles adhered to in their creation. For simplicity a single article will be

focused on. Finally we will mention preliminary feedback from students and teachers and provide an outlook of future work.

2. Article design

This section discusses the selection criteria for articles to be developed for C21, the structure of articles on the site and implementation of effective pedagogy in their creation with reference to the Vision and Diffraction article under the Biology and Medicine topic.

2.1 Article selection

Articles are chosen for C21 according to the need for resources, relation to the real world, and applicability to curriculum. The Vision and Diffraction article discusses the effect of pupil size on the minimum angle of resolution and explains how this contributes to birds of prey such as eagles being able to see distant objects more clearly than we can.

Further extensions to how the eye compares to a CCD camera are also given for teachers that may want to discuss this. This article was created because diffraction through a circular aperture is a subject which students typically have difficulty with both in terms of the physics concepts and appreciation of relevance. In other words it is a topic where we 'lose' the students quickly.

Though an article may be best suited for a certain student audience (grade or year at university) most topics have a layering of physics concepts where elements of almost any article can be of benefit to someone seeking a connection between the real world and the article subject in general. The Vision and Diffraction article in its entirety is meant for first year undergraduate physics but the concepts of the role light plays in vision and

the similarity of the design of CCD cameras to the eye could be treated at an earlier level. A discussion of diffraction and the geometrical principle of Rayleigh's criterion could also be made without reference to interference explicitly or to any formula.

2.2 Article structure

C21 articles are centered about an 'overview' that has accompanying resources as suited such as lecture notes, multiple choice (clicker) questions, problem sets and take home experiments.

2.2.1 Overview

Overviews provided detailed explanation of physics concepts centered about a 'hook', which is a question or a statement that catches interest and relates to the real world. The hook for the Vision and Diffraction overview under the Biology and Medicine topic is "Why can eagles see distant objects more clearly than we can?" [6]. Having a hook helps to provide motivation for learning the material and relates the topic to be discussed with a real world situation.

At the start of the overview keywords, curriculum connections, goals, big ideas and tools needed are included so that the purpose and key content of the material is clear and quickly accessible. The notes portion of the overview provides the main explanation with detailed references for any assertions or facts provided given at the end.

The overviews are meant for teachers and there are assumptions of prior knowledge and familiarity with the subject that students might not have. For example the Vision and Diffraction overview assumes an understanding of the general principle of diffraction. Understanding of refraction and the wavelength dependence of light on the medium through which it propagates is also assumed, though emphasis is not placed on these

concepts because the focus of the article is on diffraction. That being said if a teacher has filled in the necessary gaps then the overviews could be suitable reading for students. For this reason the language used through out the overviews as well as all the resources tries to consider the needs of students as well. We will briefly discuss key pedagogic principles for language and visuals as applied to the creation of the Vision and Diffraction overview, though these principles apply to all resources for all articles.

Language considerations

The language used tries to avoid unnecessary jargon or high language. If technical terms are introduced they are defined as much as possible in a way that the students can relate to from prior knowledge or from their own experiences and with accompanying figures [7]. The Rayleigh criterion in the Vision and Diffraction overview, for example, is explained with text and with several accompanying figures (see Figure 1 and Figure 2 with captions given in the article) where the presence of a central maxima hitting the back of the retina when looking at a point source was discussed earlier in the article. To help them feel comfortable with point sources they are asked to think of two point sources of green light as being two green points on a piece of paper.

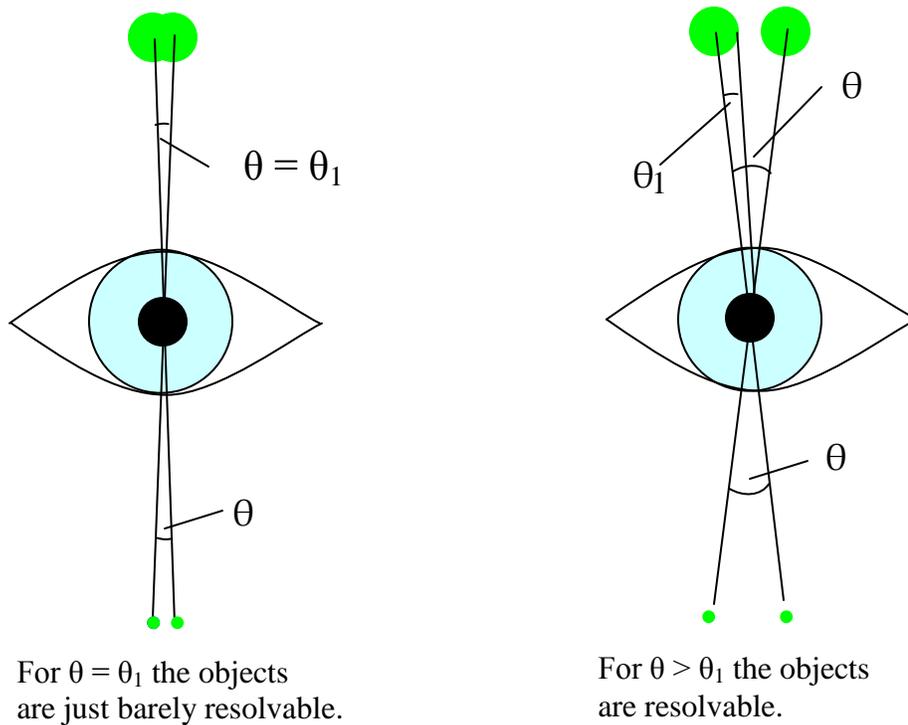


Figure 1: Caption from overview: Light from two point sources enters your eye making an angle θ with respect to your pupil. Two central maxima caused by diffraction of light entering the pupil fall on the retina at the back of the eye. The central maxima also subtend an angle θ at your pupil. θ_1 is the angle subtended by a central maximum from center to edge. According to Rayleigh's criterion, the point sources are resolvable if $\theta \geq \theta_1$.

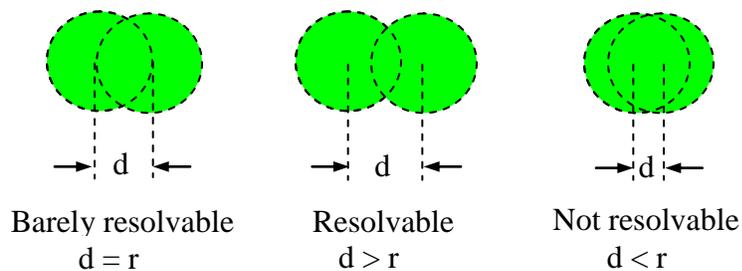


Figure 2: Caption from overview: The distance, d , between the centers of the central maxima as compared to the radius of the central maxima determines resolvability.

If assumptions or simplifications are being made they are explicitly stated, such as in the Vision and Diffraction article where we are assuming no defects in eyesight due to aberrations in the lens or cornea and we only discuss monochromatic light.

What is handed down by authority should be noted so that students know what is expected of them in terms of their own understanding. The expression of the angle the central maximum subtends from center to edge at a circular aperture for example is not proved in the overview and it is stated that an upper level optics course would be needed to derive it. For the curious teachers links are posted and references provided for their benefit.

Visuals considerations

Visuals give an opportunity to share with students the same mental images that we have as experts and that are key to our understanding [5]. Figures, demonstrations and simulations are most effective when designed to focus student attention on the key elements even if it means fictionalizing the visuals slightly or hiding away aspects [8]. For example, in Figure 1 and Figure 2 shown above from the Vision and Diffraction article, only the central maximum is shown and not the other bright rings for simplicity and clarity.

When possible, real photographs are provided along with ‘cartoon’ drawings. Figure 3 illustrates this where in the Vision and Diffraction overview a picture of a human eye showing the pupil is given with a cartoon version showing the pupil right beside it.

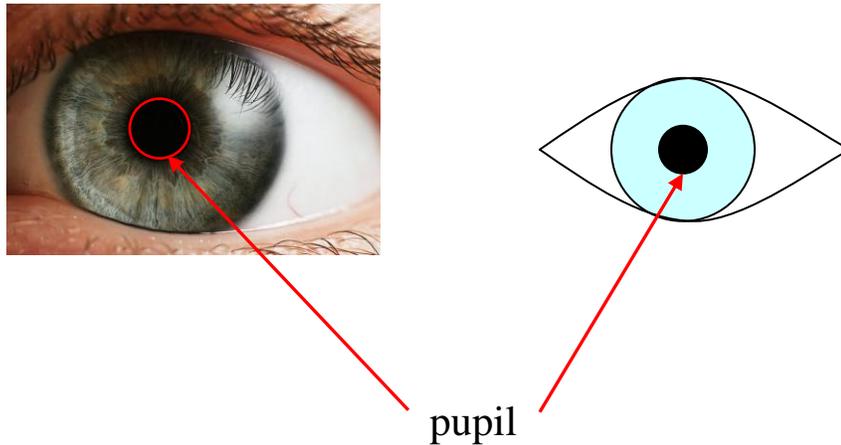


Figure 3: Example from the Vision and Diffraction overview of using real life pictures to help students identify with the simplified cartoon drawings.

2.2.2 Resources

Resources were created to help save the teacher time and demonstrate possible ways that the overview might be approached pedagogically. Note that the resources are mostly ‘stand alone’ meaning that a teacher could use any one of the resources without the need to use any other or even the overview if sufficiently familiar with the subject. Possible resources include lecture notes, multiple-choice (clicker) problems, problem sets and take home experiments. All the resources provide solutions and are editable so that teachers can adapt them to their own style and intended usage.

The resources support questioning and exploration methods promoting generative learning where the student is actively thinking about the concepts, organizing them in their minds and relating them to their experience or previous understanding [9].

In this section we will briefly discuss each type of resource associated with an overview.

Multiple-choice problems

Multiple-choice problems (clicker questions) are a powerful tool for interacting with a large class under time constraints. They are well suited for conceptual design, provide an opportunity for the class to digest what has been recently taught and participate anonymously. They also provide feedback to the students and instructor so that misunderstandings can be dealt with and teaching adjusted [9].

Clicker questions are most effective when they are conceptual rather than pure recall or calculation [4]. Possible uses are to target points that students would otherwise overlook, focus student attention on key concepts, or deal specifically with known common misunderstandings. Beatty et al. point out that when designing a question that is conceptual it may be counterproductive to include a calculation because students get wrapped up in getting the right number [4]. The C21 multiple-choice questions are designed to bring forward the key concepts of the material and typically do not involve explicit calculation. Figure 3 shows a multiple choice question from the Vision and Diffraction article with solution that addresses the main concept of the effect aperture size has on the minimum angle of resolution.

Question 3

Vision and
Diffraction



Would you be able to resolve two points on a piece of paper from further away with a smaller or larger pupil?

- a) Smaller
- b) Larger
- c) Pupil size doesn't matter

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Question 3 Solution

Vision and
Diffraction

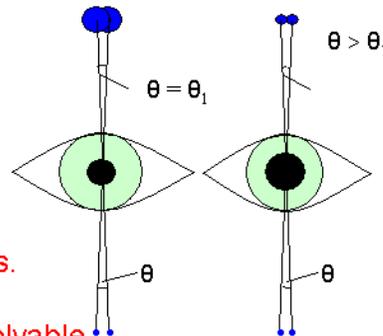


Would you be able to resolve two points on a piece of paper from further away with a smaller or larger pupil?

- b) Larger

$$\theta_1 = 1.22\lambda/D$$

As diameter D of pupil increases, min angle of resolution θ_1 decreases. The points can be further away and still resolvable compared to a smaller pupil size.



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Figure 4. An example multiple choice question from the Vision and Diffraction article.

If the material is building on prior knowledge quick multiple choice questions before new material is presented can help refresh prior knowledge. The Vision and Diffraction topic relies on an understanding of angular size which is a difficulty for many students. A clicker question is included asking “As two points on a piece of paper are moved towards you how does the angle the points make with respect to your eye change?” This should be a very simple question for most but it might prime the students’ thoughts so that the necessary logic is already in place when an explanation of why larger pupil size would lead to better resolution of distant objects is given.

Problem sets

The problem sets are more geared towards calculation problems but still require understanding of the concepts and strengthen problem solving techniques such as visualization, algebraic representation of quantities, algebraic manipulations and use of geometry. With calculation problems it is important that the results be meaningful and something the students can relate to [4]. The Vision and Diffraction asks the students to compare based on diffraction how far away they would be able to resolve two point sources versus an eagle which is an interesting comparison.

Problem sets are also suited for asking conceptual questions that require deeper thought than time allows with a clicker question or that ties an entire topic together after it has been taught.

Take-home experiments

By performing take-home experiments students are able to physically apply what they have been taught and solidify their understanding. The take home experiments explicitly outline the purpose, key concepts, materials needed and the skills used. Background

information is included again to help the resource be useable without needing to use other aspects of an article. The challenge section is where the students are asked to perform some task. For the Vision and Diffraction take home experiment the task involves comparing the distance measured at which a student would still be able to resolve two lines on a piece of paper to the distance predicted according to Rayleigh's criterion. Questions are asked that can be answered before or after the exercise. Predictive questions included can with very small time investment add engagement to traditionally passive exercises such as demonstrations or take-home experiments where a student may blindly follow instructions [10]. An example of a predictive question from the Vision and Diffraction take-home experiment is "How will what colour marker you use affect your result?" Possible sources of error are also asked for to help students see why the real world is so complicated!

Lecture notes

This is a difficult resource to develop for the many different teaching styles that exist and the many possible presentations of the topics on C21. The lecture notes produced based on power point format distill a topic into main points and figures. Specific attention is paid to visual simplicity, logical progression of ideas, adherence to key concepts and cognitive load. The lecture notes start with slides for goals (see Figure 5 for an example) and 'big ideas' outlining the purpose of the material and the main concepts.

Goals

Vision and Diffraction

- Biology: To learn about the effect of pupil size on the ability to see clearly at large distances.
- Physics: To discuss the limits of visual resolvability imposed by diffraction of light through the pupil of the mammalian eye.

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Figure 5: A slide outlining the purpose of the lecture from the Vision and Diffraction article.

3. Perspectives from students and teachers

Preliminary results from surveys and interviews of first year undergraduate physics students, secondary teachers and post-secondary teachers show favourable response to the concept of the C21 project as well as the materials created. Detailed information on responses given by teachers is presented in the honours thesis of Brittany Tymos [11] and a detailed review of student's comments is underway by Dr. Rachel Moll.

In support of the relevance of the C21 project, teachers indicated their priorities were to teach the physics concepts and to relate the concepts to the real world. The students also felt that physics was more interesting and easier to understand when connected to the real world. At least 80 percent of 36 students surveyed found the articles presented to them (there were a variety from all the C21 topics) as interesting

and/or relevant [12] . They also indicated that they would want to learn more about the topics and felt they were likely to use the information in the future.

In its entirety teachers indicated that a particular topic on C21 may be too long to go through all the resources given and too complex if all the information in a topic was to be covered. The C21 website is meant as a resource not as a prescription for teaching so that it is expected that teachers will pick and choose what elements of an article they want to discuss and what resources they feel are most beneficial or that they have the time for. A consistent majority of teachers however said they would use something from the C21 project which supports the relevance and usefulness of the materials designed for the project.

4. Summary and Outlook

In summary, the C21 project aims to use a variety of sound teaching practices in the creation of their teaching materials. These include purposeful design, clear and simple visuals and explanations designed for novices, attention to potential for cognitive overload and questioning methods with a conceptual focus.

To date we have a number of articles already on the site (18 energy and environment, 7 biology and medicine, 4 skills and techniques). Future work includes the continued creation of articles, future studies to test effectiveness and to gather more feedback, adding a feedback feature on the website, and the addition of more types of resources such as videos. Specific attention during the creation and revision of articles will be paid to the feedback already provided from students and teachers and with attention to key pedagogic principles as outlined in this paper based on literature research into the design of effective materials.

References

- [1] Redish, E.F. "Teaching Physics With the Physics Suite", University of Maryland, p.61
- [2] Perkins, K.K., et al., "Towards characterizing the relationship between students' interest in and their beliefs about physics", 2005 Physics education research conference
- [3] Lin, Y., et al., "College Student Intrinsic and/or Extrinsic Motivation and Learning", Paper presented at the Annual Conference of the American Psychological Association (107th, Boston, MA, August 20-24, 1999).
- [4] Beatty, I.D, et al., "Designing effective questions for classroom response system teaching", Am. J. Phys. 74 (1), January 2006
- [5] Wieman, C., et al., "Motivation for using real-world examples in the classroom", Phy. Today, 2005, Vol 58, No. 11, pp. 36-41.
- [6] <http://c21.phas.ubc.ca/article.php?id=122>
- [7] Gee, J.P, "What video games have to teach us", pp. 106-107, Palgrave Macmillan, 2007
- [8] Perkins, K., et al., "PhET: Interactive Simulations for Teaching and Learning Physics", The Physics Teacher, Vol. 44, January 2006
- [9] Mayer, R.E., et al., "Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes", Contemporary Educational Psychology, 34 (2009), 51-57
- [10] Crouch, C.H., et al., "Classroom demonstrations: Learning tools or entertainment?", Am. J. Phys. 72 (6), June 2004
- [11] Tymos, B., "Physics Teaching for the 21st Century: Developing Resources to Connect Physics to the Real World", Honours Thesis
- [12] Dr. Rachel Moll, private communication