Motivation and Evidence for Screen Reader Accessible Website as an Effective and Inclusive Delivery Method for Course Content in Higher Education

Dr. Vijesh J. Bhute, Imperial College London

Dr. Vijesh Bhute currently leads 1st and 2nd year modules on Mathematics in the Chemical Engineering Department at Imperial College London. He leverages technology to enhance delivery of abstract concepts and also uses math-aware assessment platforms to improve student learning. He collaborates with students on various projects and has also contributed to development of innovative hybrid experiential learning approaches. He was elected Fellow of the Higher Education Academy in 2021. He was recently recognised with Imperial College's President Award for Excellence in Teaching Innovation for his effort on developing accessible resources and use of state-of-the-art technologies for delivering engaging content.

Ellen Player
Dr. Deesha Chadha, Imperial College London

I currently work as a senior teaching fellow in the department of chemical engineering at Imperial College London having previously worked in academic development for a number of years at King's College London

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Authors: Vijesh J. Bhute*, Ellen L. Player, and Deesha Chadha

Affiliation: Department of Chemical Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ, UK

***Corresponding Author:** Dr. Vijesh J. Bhute

Address: Room 1M17A, ACE Extension Building, Department of Chemical Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ, UK

Email: v.bhute@imperial.ac.uk

Abstract

Course books containing mathematical equations and images when delivered as physical copies, scanned ebooks or PDFs are not screen reader accessible. Current frameworks for classification of learning resources assume ‘equal’ access and ‘uniform’ engagement by students but lack consideration for student preference as well as inclusivity. In this study, using feedback from students and evidence-based design principles, we have developed a screen reader-accessible website to deliver Engineering Mathematics to second year undergraduate students. Student surveys and usage statistics on the website indicated high level of engagement throughout the year with students shown to prefer this delivery method over PDF options. We have further extended the implementation to first year Mathematics course and propose a practical four-factor framework of ‘accessibility’ which can influence engagement and access by students. The proposed framework can be used to choose appropriate learning resources and screen reader accessible website can serve as a simple method to facilitate an accessible and inclusive learning environment for students.

Keywords

Teaching/Learning Strategies, Accessibility, Inclusivity, Distributed Learning Environments, Online learning, Course design

1. Introduction

1.1 Background

The use of Virtual Learning Environments (VLEs) have enabled us to organize learning resources and disseminate information to students with positive impacts in their motivation to learn [1], [2]. Importantly, analytics from VLEs such as clickstream data can be used to predict at-risk students [3], [4] as well as academic performance of students [5], [6]. VLEs are primarily used as a repository for teaching materials but recently, integration with applications such as Turnitin, VLEs have also been used for assignment submissions and grading [7].

Although VLEs have significantly streamlined the user experience, several learning resources are currently only available exclusively in libraries in the form of physical textbooks [8]. These textbooks and other course notes are reliable sources of information for students and allow them to supplement their understanding of materials taught in lectures. Several frameworks have been developed to categorise learning resources based on their use ([9], [10] in different stages of learning [11]–[13]. One of the key limitations of these frameworks is that they assume 'uniform' availability and accessibility of resources. In practice, this is not the case with several studies highlighting the importance of availability of resources on student learning [14], [15]. A framework to categorize resources based on differences in accessibility is currently lacking.

Textbooks are often recommended by teachers to supplement student learning outside the lectures. Open textbooks and e-books have been used by several institutions to provide free access to textbooks in an online format [16]. Most teachers also offer their course notes in the form of PDFs. E-learning resources such as scanned versions of textbooks, PDFs, or eBooks may not always adhere to the Web Content Accessibility Guidelines (WCAG) [17] as the original design intent was for physical publication. With increased availability of these online resources, it is paramount to heed accessibility guidelines and create an inclusive learning environment for all users. This entails ensuring resources are perceivable, operable, understandable, and robust so that people with disabilities can also use them effectively [18].

While the traditional PDFs or scanned versions of textbooks are often used by students offline after downloading to their device, the users interact with them in a similar way as they would with any online content. Therefore, it is important to assess whether content can be read accurately using assistive technologies such as screen readers. Importantly, e-resources (PDFs, scanned textbooks) used in science, technology, engineering, and mathematics (STEM) often involve mathematical equations and images and fail to be read and dictated accurately by screen readers [19], [20]. This can disadvantage those who rely on screen readers for their learning including those with learning disabilities, with eye dysfunction and personal preferences [19].

Significant emphasis has been placed on education providers to make content accessible and inclusive for all students including those with specific learning disabilities [21]. Report from Equality and Human Rights Commission have recommended schools and institutions to make reasonable adjustments to prevent disadvantages to students [22] echoing the mandates by the Special Educational Needs and Disability Act (SENDA) 2001 [23]. This is especially needed in STEM subjects where the content delivery and design may suffer with accessibility and inclusivity issues owing to the presence of mathematical equations and visualisations of abstract concepts. Having accessible learning resources not only benefits for example students with learning difficulties who would make use of screen readers or visual aids but all students by improving the quality of content [15], [24], [25].

Recently, course notes have also been delivered via Jupyter Notebooks [26]–[30]. These notes can provide real-time interactive content, visualisation, and feedback which can extend their use in the construction stage of learning [12], [13], however they require significant support, set-up time, and from an instructor's point-of-view, requires expertise or a background in programming, hence, their usage has been limited to computing and mathematics courses [30].

Online websites have also been used in the past two decades to deliver course notes [31]–[33]. Website developers undergo a special requirement of making the content accessible by following the latest recommendations provided in WCAG [17]. Websites can offer a more accessible alternative to PDF notes. In addition to being screen-reader accessible, websites offer significant advantages over traditional PDF notes which are summarised in Table 1 [34].

Table 1: Comparison of Website with PDF for delivering content.

	PDF	**Website**	**Potential Impact of transformation to website**
Screen reader accessibility	Not for images and mathematical equations	Yes	More inclusive
Navigation on small screens	Difficult (need to scroll and zoom)	Content resizes to accommodate different screen sizes	Navigation is easier on multiple devices
Interactivity	Limited	Several features (e.g., dropdown menu, videos, podcasts, animations,	Can enhance interactivity

		quizzes, forms, etc.) can be added easily	
Page size	A4	No limitation	Can influence student learning behaviour
Location of images	Not always feasible to put next to relevant text	Feasible to put next to text and click to enlarge image	No need to change pages
Content updates	Difficult to edit and changes do not sync for students	Easy to edit and changes sync for all students in real-time.	Content accuracy can be ensured effectively
Usage Statistics	Not available	Available	Can learn about student engagement and learning behaviour
Ability to link different sections	Yes	Yes	No change
Familiarity	High	High	No change
Printer-friendly	High	Medium	PDF versions of websites (offline alternatives) should be made available
Annotation	Easy to highlight or add a note	Need plugins (e.g., hypothesis.io) which may need registration	
Require internet connection	No	Yes	

1.2 Related work and considerations

There are several web-based resources available for learning. The novelty of this work lies in adapting the existing resources to make them accessible. There are several aspects which should be considered when delivering content via website. From a students' point of view, cognitive load is an important aspect of introducing any new technology [35]. Integration of too many animations and interactivity can lead to increased cognitive load [35] and potentially disadvantage those with slow internet speed [36]. Therefore, the use of animations and videos should be minimal and appropriate links can be included to ensure that time to load a page is minimal [37]. Competence for internet skills can vary and potentially also influence internet use [38], it is important to provide sufficient support to highlight different features and usage to improve student engagement [39].

The website pages should also be offered in PDF format as back up for those students who may not have stable internet connection or for those who may prefer to study offline. This PDF conversion can be done with minimal effort by, for example, exporting webpages as PDF and making them available for offline use.

1.3 Context

Department of Chemical Engineering offers a 4-year integrated Master of Engineering (Meng) degree at Imperial College London. The student body comprises of more than 50% international students. The academic year is divided into two teaching terms: Autumn (3/10/2020-18/12/2020) and Spring (9/1/2021-26/3/2021) with exams conducted during the summer term. The autumn and spring term is separated by Christmas break. Summer term is preceded by Easter break which is primarily used for preparation of the final exam which is held in the last week of April till first week of June. The Engineering Mathematics course is a compulsory module for second year undergraduate students and consists of three distinct topics: Multivariable Calculus and Field Theory (P1), Fourier Analysis and Partial Differential Equations (P2), and Probability and Statistics (P3). There is very little overlap in the concepts taught in the three topics and hence, traditionally the course is taught by three teachers in parallel during the year. P1 and P2 are both taught in the autumn term only while P3 is taught in both autumn and spring terms. The course has several non-graded and graded assignments during the year and a summative final exam in May [40]. The course notes are usually presented as three separate PDF files with differences in formatting. This study aimed to develop a uniform course book and explore the following key questions:

a) What factors affect students' level of engagement with a learning resource?
b) How is students' experience with screen-reader accessible website which is used to deliver Mathematics courses?

In this study, we have gathered anonymous questionnaire responses data from students and teachers from Imperial College London to understand usage of resources by students and teachers and student outlook for a potential course website as a learning resource. We have developed a screen reader accessible website to deliver course notes for the second year undergraduate Mathematics course to improve accessibility of content. We also used population level Google analytics to gain insights into student learning behaviour and gathered anonymous student feedback to learn about their preferences. Based on this feedback, we have proposed four factors to consider when developing learning resources in the current age with accessibility and inclusivity as the primary objective. These factors are cost, sense of ownership, effort to access, and screen reader accessibility. Our data indicates that a screen-reader accessible website meets these proposed factors and can potentially be used to deliver course notes in STEM subjects to create a more accessible and inclusive learning environment.

2. Methods

2.1 Survey and participant details

Survey research method was used to address the aforementioned questions. Three individual surveys were created for the study and each of these can be found in the Supplementary File 1. No identifying information was requested in these surveys and participation was voluntary.

Ethics approval was received from the Education Ethics Review Process Team prior to conducting this study.

Questionnaire 1 was distributed to teaching staff via Teaching and Learning Network on MS Teams. 34 teachers participated in this questionnaire from different departments across the College. Questionnaire 2 was distributed to second-, third- and fourth-year undergraduate students from the Department of Chemical Engineering who have experience with university learning. 55 students (~14.4%) participated in this questionnaire across these three year groups. Both questionnaires 1 and 2 were launched at the beginning of the academic year.

Questionnaire 3 was distributed to second year undergraduate students in the Department of Chemical Engineering at the end of teaching Engineering Mathematics for the academic year of 2020-21. Second year students were introduced to the course website and hence, were chosen for this questionnaire to gather feedback. 21 students (out of 143 in the class, 14.7%) participated in this voluntary questionnaire.

Questionnaire 2 and 3 consisted of few common questions to compare the aggregate views of participants before and after the experience with website. Anonymous link generated by Qualtrics was used for distribution. In addition to these surveys, some students also provided anonymous voluntary feedback for the website in the 'feedback' section of the end of term course evaluation.

2.2 Website design, features, and support

A design-based approach [41] was used to develop a screen-reader accessible website. The website hosted on the Atlassian Confluence server but in theory, can be hosted via open-source and free services (e.g., GitHub). The website compiled the three separate PDF files for P1, P2, and P3 sections into a single platform. To ensure screen-reader accessibility, mathematics equations and symbols are rendered using a LaTeX/MathJax form and equation numbers are kept in a similar format as the original LaTeX rendered book using a custom-built HTML segment. The website is divided into sub-topics and chapters with each webpage containing a different subtopic. Consistent formatting is used throughout the website. Atlassian confluences' default font type is used for text but the font size for main body text is increased to 18pt. This font size was chosen based on font size guidelines for websites which are text-heavy [42]. Headings and titles are also increased in size.

While the content was kept largely similar to the content in the PDF course book, there are several features which differentiate this website from the PDF notes. Coloured boxes are used to highlight important information such as headings (purple), theorems (blue), examples (yellow), and definitions (green). These were kept consistent through all the chapters on the website. The colours chosen are based on recommendations from Web Accessibility Initiative (WAI) and are compatible and helpful to a wide range of people including those with learning disabilities [43]. Examples are designed to be interactive with a drop-down link to show the full solution, thereby encouraging students to try the examples on their own first before viewing the detailed solution. All changes to the look of the website as mentioned above are implemented via a custom-made cascading style sheet (CSS).

As discussed before, the location of figures is not constrained by space in the page. Therefore, each figure is positioned next to where it is first referred in the text. Additionally, the figures are clickable which results in high resolution image that can be zoomed in for better view. Alt-text is added to figures to make them accessible via screen-readers. Horizontal scrolling can add burden to readers and impact comprehension [44]. The website automatically configures text to match the screen size and hence avoiding the need for horizontal scrolling. Importantly, when the window size is made smaller (for example for split view), the equations are coded such that they split into multiple lines in a sensible manner to further avoid horizontal scrolling. Navigation to next or previous sub-topic is available on the top and bottom of each page. There is a navigation panel for navigating the whole website on the left of the page and each individual page has hyperlinks within the page to navigate to different subsections. The website also contained several Microsoft forms iframes to allow students to raise an alert on any issues such as spelling mistakes and errors as well as offer anonymous feedback by rating the website from 1 to 5 stars and enter free-text entries via an open text general feedback box.

A video explaining how to access the features is added on the website and a link to this video is also provided to students. Closed captioning was provided with manually curated captions. A frequently asked questions (FAQs) page is included to further clarify common questions which students might have with respect to website navigation and access. To annotate the website and share notes, we implemented an online plugin [45] and added relevant information about its use in the main page and the FAQ page. It is important to mention that all content on the website is also made available in PDF format for students and these PDF files are available for download via BlackBoard Learn (BBl) and MS Teams. This is done to provide options for accessing the content offline.

Google analytics are used on the website to gain insight into usage statistics. All data is anonymised, and students are notified regarding the data usage wherever the link to the wiki is posted. Survey data and Google analytics data is exported in MS Excel and is further analysed using IBM SPSS Statistics for Windows (version 26). Anonymised user views to introduction video are also used for analysis.

3. Results and Discussion

3.1 Students indicate higher ease of access for website and similar preference when compared with PDF notes

We asked undergraduate students to rank their usage of different resources provided by their teachers. PDF Notes was ranked first by more than 60% of the respondents to be most used resource while textbook from a reading list was ranked as the least used learning resource (Figure 1a). The next preferred resources after PDF were all online websites, either provided by the teacher, or student or other online resources. Majority of students ranked printed notes at the fifth position.

We asked students whether they had any preferences in terms of learning resources, if different resources are made available (to overcome the differences in availability of resources), and respondents ranked PDF and websites as their top two preferences (Figure 1b). We also asked students to rate the ease of accessibility of different formats of delivery (Figure 1c). Websites were found to be extremely easy to access followed by PDFs, printed and textbook indicating benefit of using websites to make the content more accessible to students.

Printed notes, a resource previously provided in this course, was the third preferred option for students. Some respondents reported printed notes to be ‘extremely easy’ to navigate and highlights the relevance for a smaller proportion of students who prefer to print notes for potentially writing their own notes or highlighting with gaining the tactile feedback which is often missing from looking at the notes online via PDF viewer or on websites [39]. Therefore, it is important to include printable versions of course notes to cater to students’ preferences.

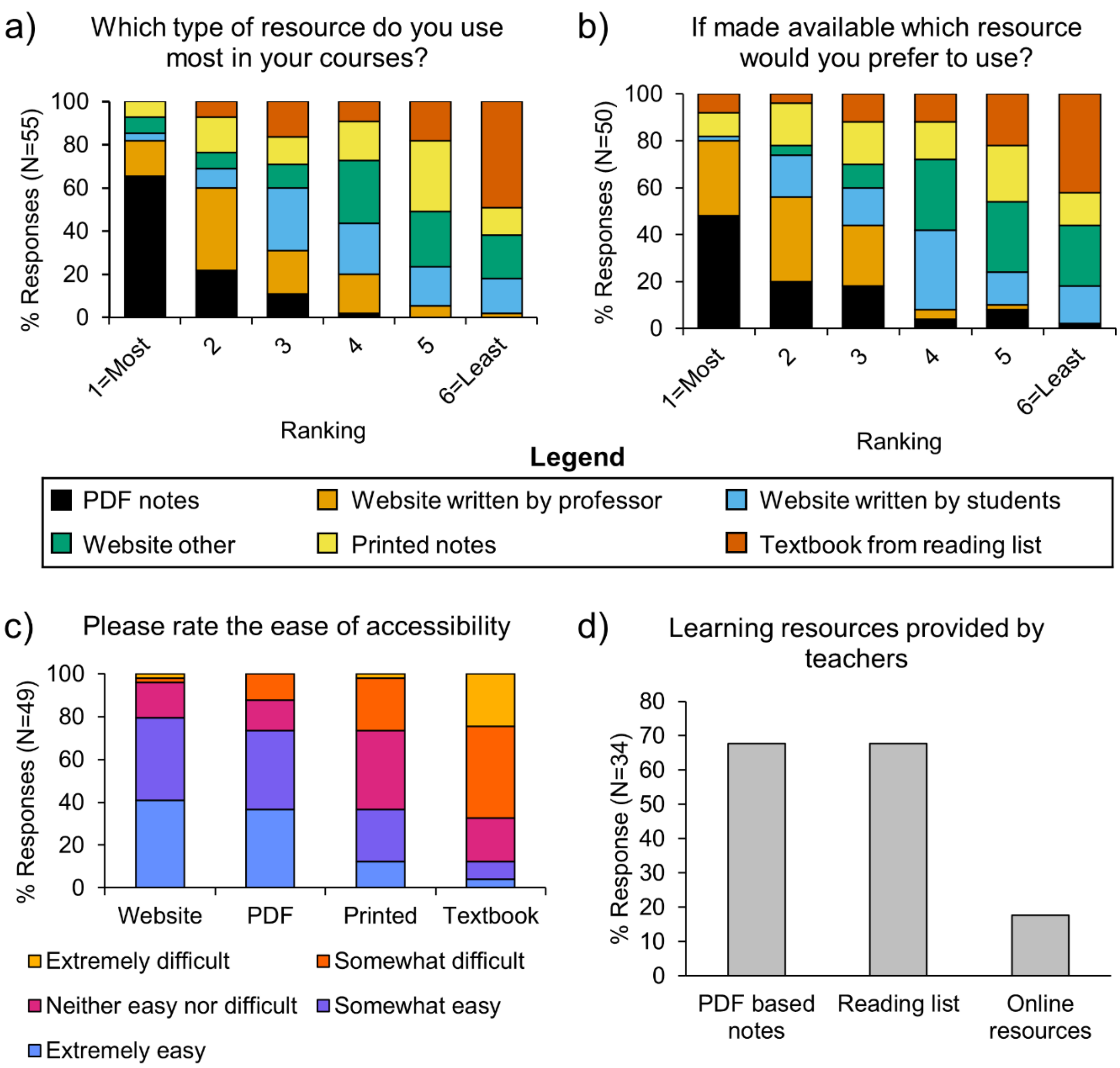

Figure 1: Usage, availability, and accessibility of different learning resources. Survey responses from students when they are asked to a) rank different types of learning modes from most used to least used (N=55), b) rank the preference of different types of learning modes from most to least preferred (N=50), and c) rate the easy of accessibility of different modes of delivery (N=49). d) Survey responses from teachers when they were asked to list the different types of learning resources in addition to lectures (N=34).

We also surveyed teachers across different faculties to provide details regarding different learning resources (in addition to lectures) and more than 60% of respondents provide students with PDF based lecture notes on the virtual learning environment BBl and a recommended reading list (Figure 1d). Based on student responses, it is evident that very few students use the resources from the reading list. Importantly, while students ranked the usage of website and online resources as one of their most used resources, less than 20% teachers provided online resources highlighting a disconnect in student preferences and teacher provided resources.

This difference was highlighted in a recent study where student searches for online resources doubled during the COVID-induced online teaching [36]. Existing learning resources including textbooks are less accessible when students are learning from home while the ubiquitous nature of internet can cater to student learning needs.

3.2 PDF containing equations are not always screen-reader accessible

LaTeX converted PDF books are traditionally provided in Mathematics-heavy courses as resources for students to consolidate their learning. We used screen reader to read the equations from PDF notes and while majority of the equations were read correctly, some equations were read inaccurately (as shown in Figure 2a). All formulae on the website, on the other hand, can be read by screen readers accurately (Figure 2b). This is due to the rendering on the website being carried out by MathJax and allowing export of selected equations without having to rely on a decoder.

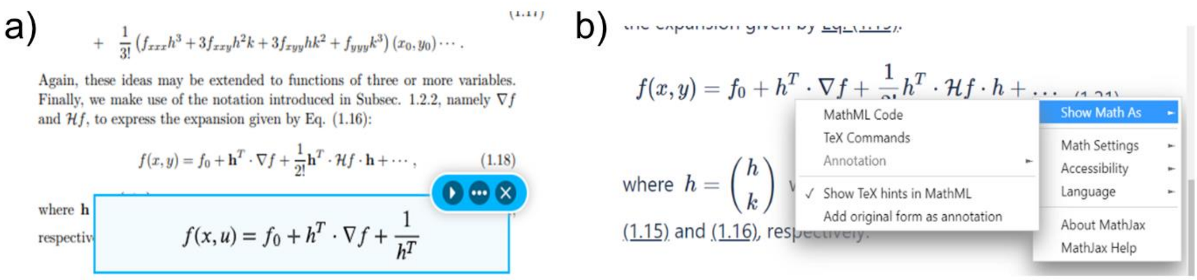

Figure 2: Mathematical equations are screen reader accessible in website. Screenshot of a) equation incorrectly recognised by the screen reader when applied on an equation contained in a PDF course book and b) the same equation when viewed on the website.

3.3 Scaffolding the transition to website

Since websites offer several benefits with respect to accessibility, we developed a website to deliver course notes for Engineering Mathematics course. Not all students find new things such as websites and educational resources intuitive and it was an important part of this research to be as inclusive to students' needs as possible. A short introduction video with closed captioning was implemented to introduce students to different features of the website and know how to reach us in case of questions. The video was available on-demand and could be accessed either directly through the website or via BBl and allowed students to control speed, use captioning, and play/pause as per their convenience. This video was watched 117 times during the year with 49 unique viewers (~34% of the cohort) highlighting that some students also watched this video more than once.

3.4 Students prefer course website over PDF

We asked second year students at the end of the academic year 2020/21 to provide their feedback on the Engineering Mathematics course website. We asked them to select the features or qualities of the website that they liked (Figure 3a). Maximum respondents (>90%) selected the ‘example-solution drop down’ which is unique to the website (when compared with PDF) indicating students liked the option to test themselves on a question and then click to reveal a worked solution. Some of the other qualities which the majority of the respondents liked were ‘definition, theorem and example boxes’ (86%), ‘organization of chapters by pages’ (86%), ‘overall look of the website’ (71%), ‘seamless navigation’ and ‘colour scheme’ (57%). A focus of the study was to enhance the screen-reader accessibility of current resources. 23.8% of the respondents reported liking the fact that the website was screen reader accessible, which is a key difference between PDF and website-based resources. This indicates the website is providing for those with hidden disabilities. We also asked students to choose the features that they didn’t like. While 14% respondents indicated that they did not like the organization of chapters on website, the majority of the respondents (>80%) didn’t select any of the options or provide any comment in the free-text option highlighting that overall perception of website was very positive.

We next asked students regarding the ease of navigation (Figure 3b) and accessibility (Figure 3c) of the website. More than 90% respondents selected that it was either somewhat or extremely easy to navigate and access the website. Importantly, we compared the responses from 2nd year students before the beginning of the course and after using the website for a year. There was significant improvement in student outlook towards the website. Both ease of navigation ($p=0.0006$) and ease of accessibility ($p=4.5\times10^{-6}$) of the website were rated significantly more favourably after a year when compared with the responses at the beginning of the year (Figure 3b and 3c). We also asked students to rate their agreement with different statements related to the preference of website over PDF notes (Figure 3d). More than 87% of the respondents liked the website format for course notes and importantly, preferred the website over PDF based course notes.

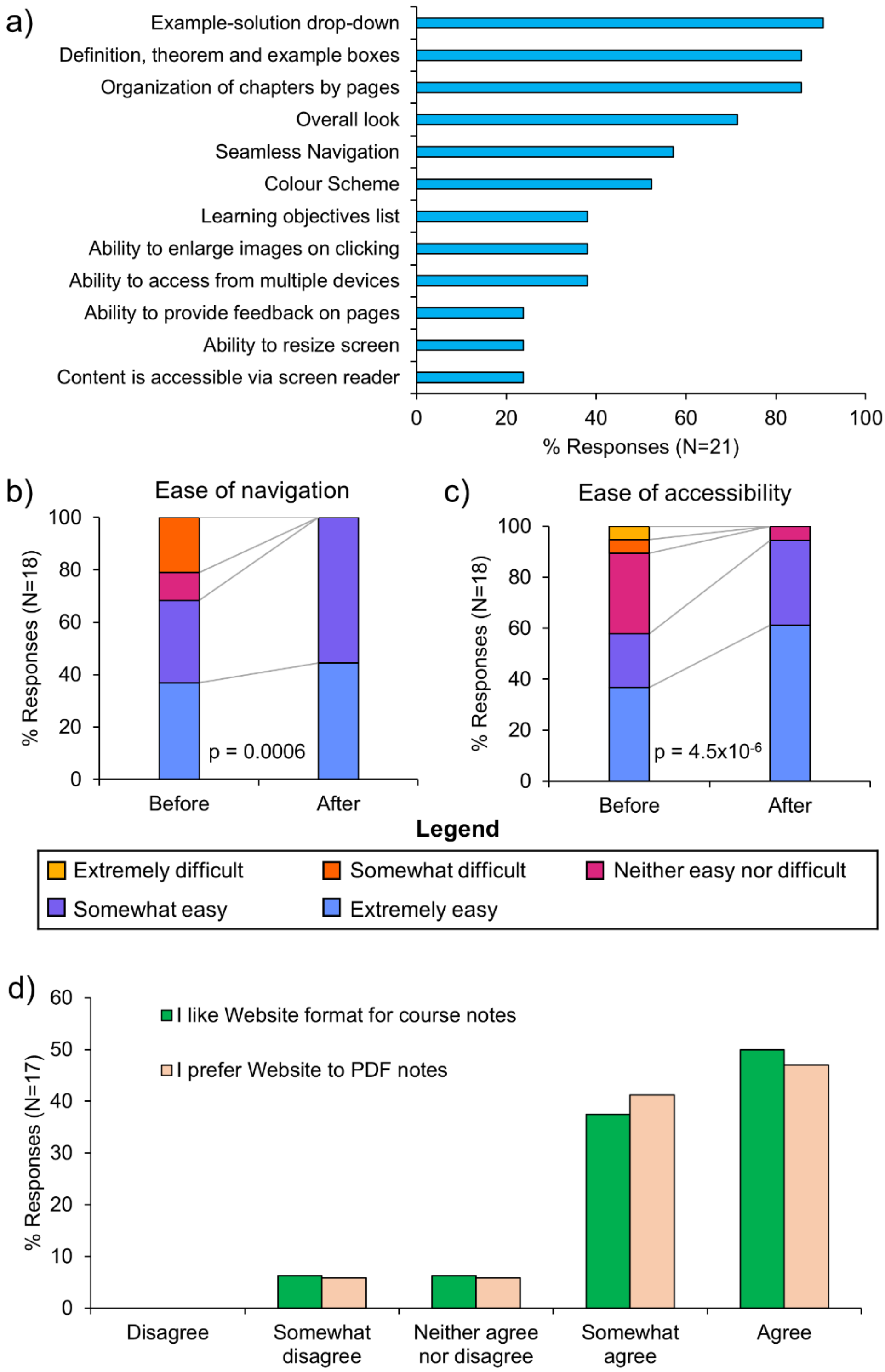

Figure 3: Students find website extremely easy to access and navigate and also prefer website to PDF notes. a) Survey responses for students when they are asked to select the features they liked about the website (N=21). Comparison of student responses before using the website and after a year of using the website on their rating of a) 'ease of navigation' and b) 'ease of accessibility' of website (N=18). Fisher's exact test is used to determine differences in distribution of responses. d) Student agreement with the statements: I like the website as a format for course notes and I prefer the website to PDF notes (N=17).

3.5 Google analytics highlights student learning behaviour throughout the year

Website usage statistics was provided by Google analytics. The non-zero value of users in the beginning of the term constitutes of the developers, teachers and teaching assistants who reviewed the website before the term began on 3rd October 2020 (Figure 4). This review process was critical to identify any errors and make recommendations for improvement on the website before it was made available to the students.

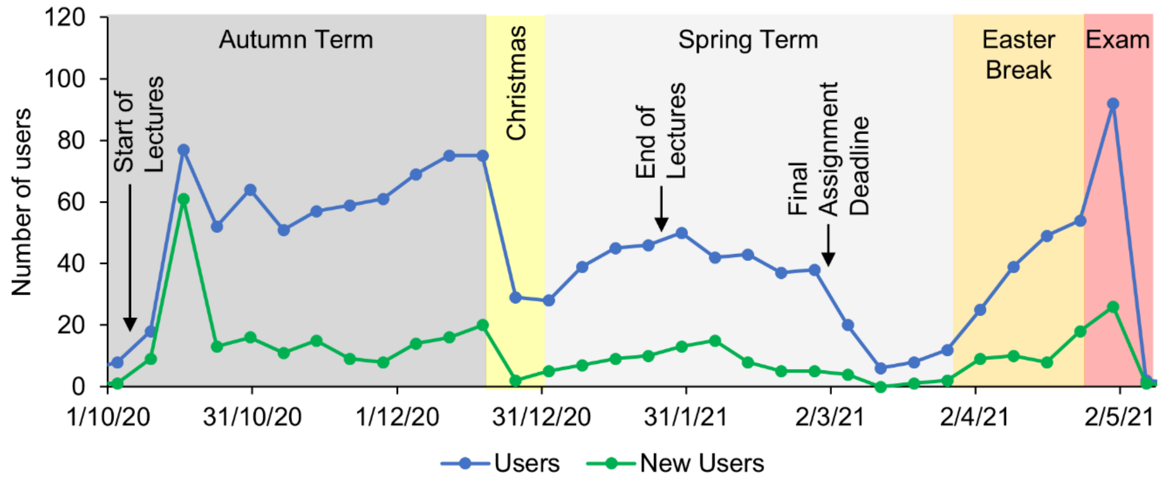

Figure 4: Website analytics indicate high engagement of website throughout the year. Google analytics data for number of users and new users accessing the website every week across the academic year.

The initial peak in new users coincided with the introduction of website with relevant links including the link to introductory video during the first lecture of the course. Majority of the teaching in the course is done in the autumn term. The total users on the website remained steady during the autumn term which highlights that majority of the students used the website during the term when the content was being taught most likely to consolidate the concepts taught in lectures. Spring term saw a decline in the number of users which could be attributed to the fact that while P1, P2, and P3 were taught simultaneously in the autumn term, only P3 was taught in the spring term. Additionally, other factors such as workload from other courses in the spring term could also attribute to this reduction in number of users on the website. Importantly, the usage of website continued after the end of lectures on 26th January until 28th February which was the deadline of final graded assignment for the course. This stresses the importance of formative assessment in engaging students with the course over the year.

The second most important period for engagement with website was during the easter break when students prepare for their final exam of the module. There is a steady rise in number of new users and total users on the website. This highlights that students used the website for revision and preparation for exams. The steep rise in users in the final week before the exam is likely due to last minute preparation for examinations. Overall, the website was highly utilised by students with a total of 5107 sessions and 16347 page views across the site during the academic year. A significant proportion of these sessions were from repeat users who logged on initially in the first few weeks of term and continued to use the website both during the term and for revision.

3.6 Students engaged with website at all stages of learning

Analytics can also offer valuable insights into learning behaviour of students as well as difficulty level of a topic/lecture. To highlight this, we studied the usage of a representative page on Fourier series (which was taught in the autumn term) during the year. The page views per day have been represented in Figure 5a (Autumn term) and Figure 5b (Easter break and exam week). The number of page views had a large peak when the topic was first introduced with highest number of views during the lectures 1-4. These lectures were also fundamental for the understanding of core concepts associated with Fourier Series. These peaks coincide with new concepts with relatively fewer views on the days of Lectures 5 and 6 which were mainly focused on applications of Fourier Series. This highlights that students referred to the course notes for further reinforcing their understanding of new concepts. The increased engagement of students with the website during the concept-heavy lectures indicates that students require more time and effort to understand these concepts. Hence, it might be beneficial to provide concept-building resources as pre-lecture and allow students to conceptualise and understand at their own pace. This usage data also supports the flipped classroom approach which emphasises on teaching concepts outside of classroom and using lectures for active learning and problem solving activities [46]–[48].

Graded formative assessments, but not non-graded assessments, have been shown to be positively associated with student performance on exams [49]. In addition to lectures, students had graded formative assessments and we observed an increase in number of views close to the deadline for non-graded assignment which is most likely by these students who attempted the assignment (Figure 5a). Importantly, we saw a continuous engagement on this page until the deadline for the graded assignment. This demonstrates students engage with course notes when solving assignments and that using graded formative assessments with appropriate deadlines can increase the engagement of students during the term.

At the end of the year and before the exams, students have one month of easter break where students prepare for the exams. We observed the highest number of views in the exam week with intermittent engagement during the easter break (Figure 5b). This highlights that students also referred to the website during their preparation/revision. Importantly, this data is consistent with student responses to “when do you access the website?” (Figure 5c). Majority of students responded that they used the website for revision, solving assignments and after lectures. These are also the times when we observed very high page views during the year. ~40% respondents indicated that they used the website before and during lectures (Figure 5c) which is also consistent with the analytics data where we observed an increase in page views a day in advance of the lecture (Figure 5a). Overall, website analytics provides valuable insights into students’ learning behaviour throughout the year.

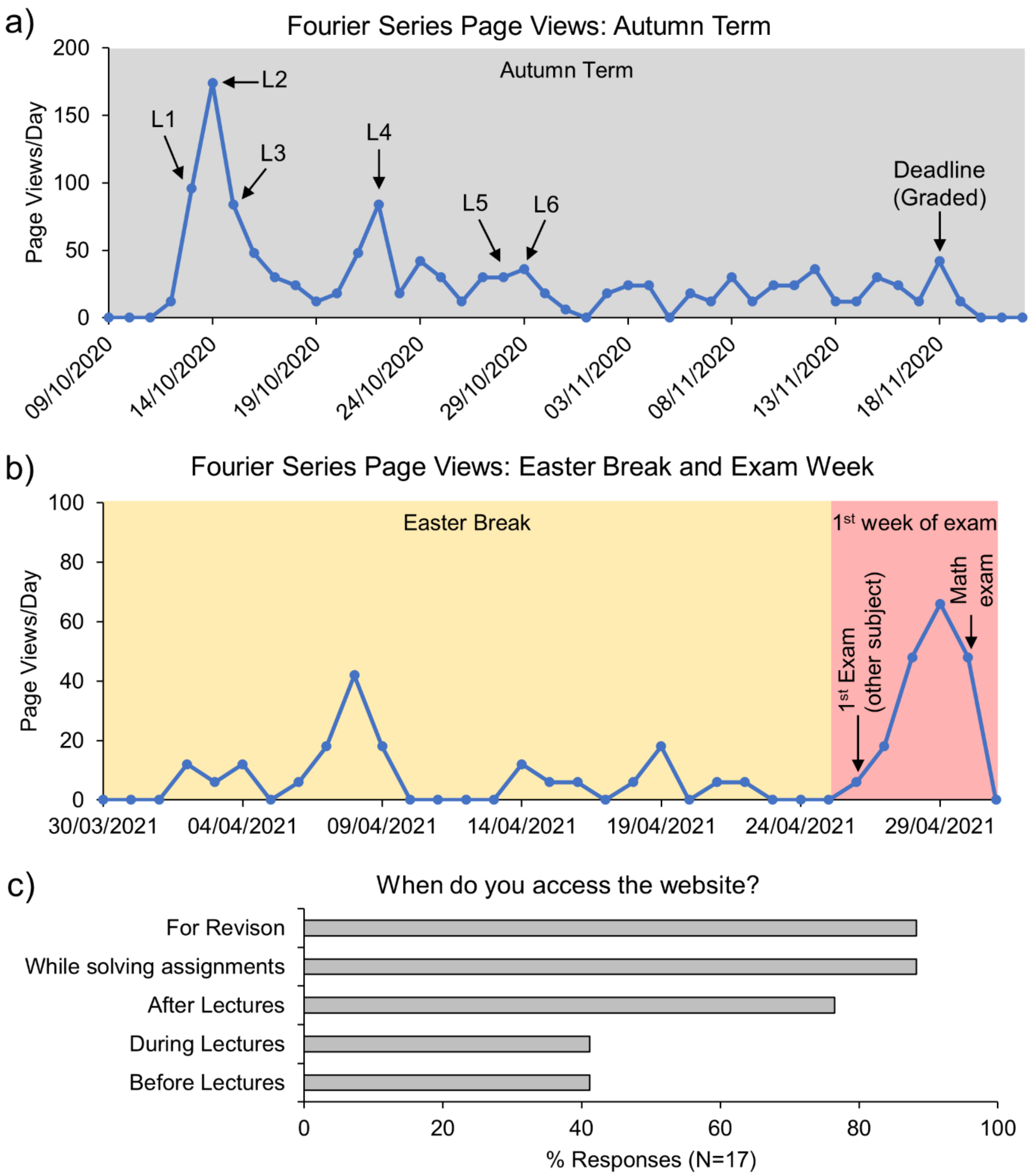

Figure 5: Website analytics provide valuable insights into student learning behaviour. Number of page views each day for the page ‘Fourier Series’ during a) the Autumn term and b) revision period. Survey data for 2nd Year student’s responses to the question c) ‘When do you access the website?’.

3.7 Framework for Accessibility

Lau et al. had proposed a useful e-learning framework to categorise e-learning resources [11]. While this framework can indicate the usage of different learning resources at different stages of learning, it does not account for availability, accessibility, and its impact on engagement. Based on student feedback on questionnaire 2 (Figure 1b and 1c), as well as engagement with the screen-reader accessible website, we have identified certain factors specifically to account for differences in student engagement with the resource (Figure 6a).

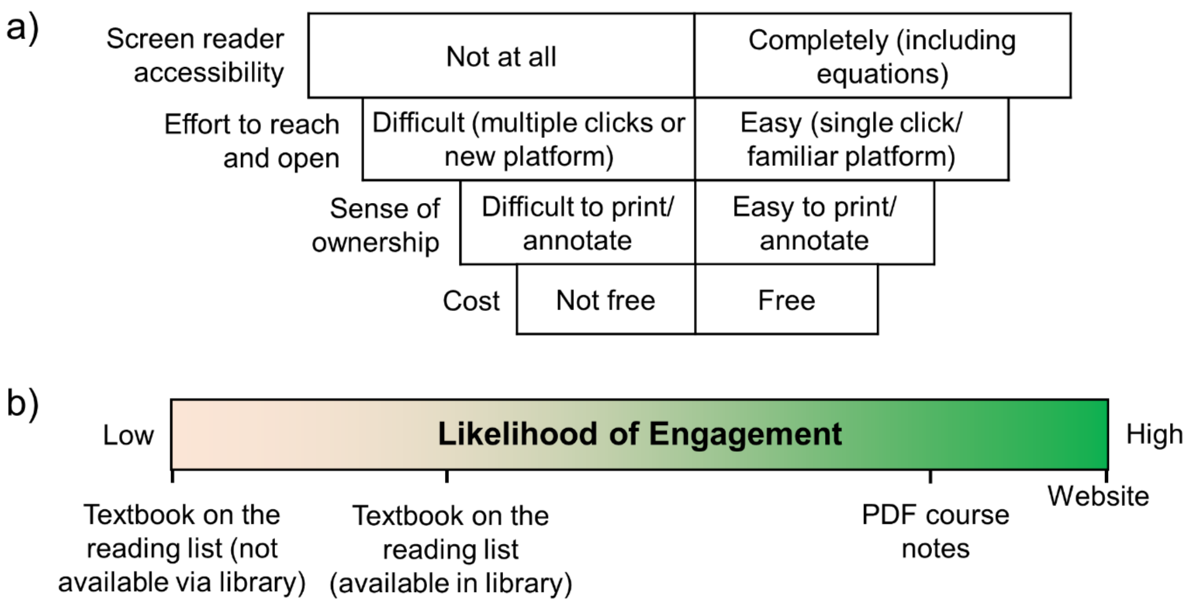

Figure 6: Four Factors of accessibility and likelihood of engagement of resources. a) The extreme scales for four factors of accessibility of a resource: cost, sense of ownership, effort to reach and open, and screen reader accessibility. b) Schematic of likelihood of engagement of different resources based on the different factors of accessibility.

We hypothesize that the low usage and preference of resources on the reading list could be attributed to their cost. Therefore, the cost of the resource is the first and a critical factor which can impact students’ willingness to engage with the resource. Textbooks on a recommended reading list and not available in the library are rarely used by students even if they can offer better personalisation and tactile feedback to students. We believe this is a major bottleneck in accessibility (Figure 6a).

The second factor is related to the sense of ownership by the students [9]. Resources which can be annotated easily and hence, personalised are more likely to be used by students [39]. Some eBooks and textbooks from library for example have copyright requirement and hence, may not be eligible for printing or making notes. These resources are again less likely to be used as compared to the editable and printable resources.

The third factor is how easy is it to reach and open the resource. Some resources are editable, printer friendly and free and yet, if it requires students to go through several steps and links to reach there, these are also less likely to be accessed and preferred by students as compared to those which are easy to reach (with as few clicks as possible). Sometimes even if the resource can be reached with a click but if it requires a special software or platform to be accessed (e.g., Jupyter Notebooks), then this further limits the ability of students to engage with this resource as students often use multiple devices to open the resources [30].

The final factor of accessibility is via screen reader. This makes the content accessible for those students who have special reading requirements [19]. Based on these factors of accessibility, we have categorized the different resources and rated the likelihood of engagement by students (Figure 6b).

4. Conclusions

4.1 Novel findings

In this study, we have provided evidence that use of basic features on a website can allow for easy transformation of existing course notes to more accessible course notes when delivered on a screen reader accessible website. This website is built in collaboration with students who use screen-readers to supplement their learning. In addition to features common with textbook such as consistent formatting of boxes for theorems, definitions, and examples, students also liked several features unique to the website including the example-solution dropdown feature, organization of chapters and overall appearance. All students responded that it was somewhat or extremely easy to navigate and more than 94% indicated that they found the website somewhat or extremely easy to access. Students also liked this mode of delivery and preferred the website over PDF notes for delivery of course notes. While several studies have emphasised preferences of students for printed or PDF notes [39], [50], we find that our implementation of website was well received by students.

We additionally made use of Google analytics to gain valuable insights into student learning behaviour and engagement with the website during the year [51], [52]. It was interesting to see that students had highest views on the days of lectures with new concepts highlighting an important role of course notes for learning new concepts which is consistent with conceptualisation stage of learning [12], [13] and also provide supporting evidence to implement flipped classroom model to in teaching [46]. We also observed consistent engagement for graded assignments as well as during the revision period suggesting their use during the construction stage of learning [12], [13]. Graded formative assessments with deadlines consequently increased student engagement with the course notes during the term. This insight supports the use of graded formative assessments for enhancing student engagement with the content. Importantly, these engagement insights also aligned with student responses on their engagement with the website.

Accessibility of content is an important aspect for student learning. Current frameworks for categorising learning resources do not account for differences in accessibility of resources [9]–[13]. We have identified four important factors of accessibility for resources which should be considered when choosing and designing the learning resources to supplement student learning. These are cost, sense of ownership, effort to reach and open, and screen reader accessibility. There is a disconnect in the resources that are traditionally offered by teachers and the level of accessibility of the resources. Websites with screen reader accessibility can offer high level of accessibility for STEM courses which are rich in mathematical equations.

4.2 Limitations

While this resource was highly used by students, it is important to note some limitations of online content. Since the website can be accessed online on any devices, it requires stable internet connection. For students with unreliable internet connections, it is important to provide alternative versions of notes which may not be screen reader accessible, but which can be accessed offline (e.g., PDF). This was provided to students in conjunction to the course website.

It is worth noting that this implementation was carried out during the academic year 2020/21. Although it is very unlikely, but it is possible that student opinions, responses, and engagement with website may be different when they are attending lectures in person. Another limitation of this study is the limited number of responses. We have provided the number of responses in each figure and figure legend (where applicable) to further emphasise that the findings are from this sample population. As with any qualitative research, it is likely that the general views of the whole population may be different, but our sampling is not forced, and the study was undertaken with ethical considerations and approval.

4.3 Future Directions

The current implementation involved clear and consistent formatting with very few basic functionalities. We will gather student feedback to learn more about new features which can further enhance student experience without increasing the cognitive load and disadvantaging students with slow internet speed. Future implementations are also expected to be during in-person teaching and the constraint of internet speed may not be relevant when students are on campus. We have also extended the development of similar course website for other courses within the Department.

4.4 Contributions

The four factors of accessibility proposed in this study can enable teachers to choose the learning resources with student engagement and accessibility in mind. We have shown a proof-of-concept that simple implementation of website with screen reader accessibility can foster an engaging, inclusive, and accessible learning environment for students. There were several design principles which were recommended in literature including reducing the cognitive load, providing training or support to those who may need assistance, considering accessibility for all readers including those with different learning abilities. We believe that these design principles can be applied in any subject and can be scaled easily with minimal resource requirement and expertise to transform existing course notes to screen reader accessible notes.

5. Acknowledgements

Authors would like to thank the Education Ethics Team for providing feedback and approval for conducting this study. Authors specially thank all the participants of surveys including teachers and students who provided their valuable time and feedback. Authors also thank Dr. Monika Pazio for helpful feedback on improving this manuscript. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

6. Supplementary information

Supplementary file 1: This file contains the surveys used in this study.

7. References

[1] D. Stricker, D. Weibel, and B. Wissmath, "Efficient learning using a virtual learning environment in a university class," *Comput. Educ.*, vol. 56, no. 2, pp. 495–504, 2011, doi: 10.1016/j.compedu.2010.09.012.

[2] J. Barker and P. Gossman, "The learning impact of a virtual learning environment : students' views," *Teach. Educ.*, vol. 5, no. 2, pp. 19–38, 2013.

[3] H. Waheed, S. U. Hassan, N. R. Aljohani, J. Hardman, S. Alelyani, and R. Nawaz,

"Predicting academic performance of students from VLE big data using deep learning models," *Comput. Human Behav.*, vol. 104, no. November 2018, p. 106189, 2020, doi: 10.1016/j.chb.2019.106189.

[4] J. Kuzilek, J. Vaclavek, Z. Zdrahal, and V. Fuglik, "Analysing Student VLE Behaviour Intensity and Performance.," in *Transforming Learning with Meaningful Technologies. EC-TEL 2019. Lecture Notes in Computer Science, vol 11722*, 2019, doi: 10.1007/978-3-030-29736-7_45.

[5] A. Al-Azawei and M. A. A. Al-Masoudy, "Predicting learners' performance in Virtual Learning Environment (VLE) based on demographic, behavioral and engagement antecedents," *Int. J. Emerg. Technol. Learn.*, vol. 15, no. 9, pp. 60–75, 2020, doi: 10.3991/ijet.v15i09.12691.

[6] R. A. Green, L. Y. Whitburn, A. Zacharias, G. Byrne, and D. L. Hughes, "The relationship between student engagement with online content and achievement in a blended learning anatomy course," *Anat. Sci. Educ.*, vol. 11, no. 5, pp. 471–477, 2018, doi: 10.1002/ase.1761.

[7] S. Burrows and M. Shortis, "An evaluation of semi-automated, collaborative marking and feedback systems: Academic staff perspectives," *Australas. J. Educ. Technol.*, vol. 27, no. 7, pp. 1135–1154, 2011, doi: 10.14742/ajet.909.

[8] D. Broadhurst, "The direct library supply of individual textbooks to students: examining the value proposition," *Inf. Learn. Sci.*, vol. 118, no. 11/12, pp. 629–641, 2017, doi: 10.1108/ILS-07-2017-0072.

[9] D. Laurillard, "Digital technologies and their role in achieving our ambitions for education," *Inst. Educ.*, pp. 1–40, 2008.

[10] D. M. Laurillard, *Rethinking university teaching: A framework for the effective use of learning technology*. London: Routledge, 2002.

[11] K. H. Lau, T. Lam, B. H. Kam, M. Nkhoma, J. Richardson, and S. Thomas, "The role of textbook learning resources in e-learning: A taxonomic study," *Comput. Educ.*, vol. 118, no. February 2017, pp. 10–24, 2018, doi: 10.1016/j.compedu.2017.11.005.

[12] C. J. H. Fowler and J. T. Mayes, "Learning relationships from theory to design," *Alt-J*, vol. 7, no. 3, pp. 6–16, 1999, doi: 10.1080/0968776990070302.

[13] T. Mayes, "Learning technology and learning relationships," in *Teaching and learning online: Pedagogies for new technologies*, T. Mayes and J. Stephenson, Eds. Kogan Page, London, 2001.

[14] R. E. Landrum, R. A. R. Gurung, and N. Spann, "Assessments of Textbook Usage and the Relationship to Student Course Performance," *Coll. Teach.*, vol. 60, no. 1, pp. 17–24, 2012, doi: 10.1080/87567555.2011.609573.

[15] A. Hidayati, "The analysis of influencing factors of learning styles, teacher's perceptions and the availability of learning resources in elementary schools in Padang, West Sumatra," in *Journal of Physics: Conference Series*, 2019, vol. 1185, p. 012149, doi: 10.1088/1742-6596/1185/1/012149.

[16] O. Ozdemir and C. Hendricks, "Instructor and student experiences with open textbooks, from the California open online library for education (Cool4Ed)," *J. Comput. High. Educ.*, vol. 29, no. 1, pp. 98–113, 2017, doi: 10.1007/s12528-017-

9138-0.

[17] “Web Content Accessibility Guidelines (WCAG) Overview | Web Accessibility Initiative (WAI) | W3C.” [Online]. Available: https://www.w3.org/WAI/standards-guidelines/wcag/. [Accessed: 23-Jun-2021].

[18] “Introduction to Web Accessibility | Web Accessibility Initiative (WAI) | W3C.” [Online]. Available: https://www.w3.org/WAI/fundamentals/accessibility-intro/. [Accessed: 04-Aug-2022].

[19] R. Browder, “Chapter 5. Scanning Print to PDF: Opportunities and Obstacles for Screen Reader Accessibility,” in *Library Technology Reports*, vol. 54, no. 4, 2018, pp. 23–27.

[20] S. G. R. Junus, “E-Books and E-Readers for Users with Print Disabilities,” in *Library Technology Reports: Making Libraries Accessible: Adaptive Design and Assistive Technology*, 2012, vol. 48, no. 7, pp. 22–28.

[21] K. A. Harper and J. DeWaters, “A Quest for website accessibility in higher education institutions,” *Internet High. Educ.*, vol. 11, no. 3–4, pp. 160–164, 2008, doi: 10.1016/j.iheduc.2008.06.007.

[22] “Adjustments for Disabled People | Equality and Human Rights Commission,” 2015. [Online]. Available: https://www.equalityhumanrights.com/en/publication-download/reasonable-adjustments-disabled-pupils. [Accessed: 12-Apr-2022].

[23] “Special Educational Needs and Disability Act 2001.” [Online]. Available: https://www.legislation.gov.uk/ukpga/2001/10/contents. [Accessed: 21-Jun-2021].

[24] J. E. McCarthy and S. J. Swierenga, “What we know about dyslexia and Web accessibility: A research review,” *Univers. Access Inf. Soc.*, vol. 9, no. 2, pp. 147–152, 2010, doi: 10.1007/s10209-009-0160-5.

[25] C. Boldyreff, E. Burd, J. Donkin, and S. Marshall, “The case for the use of plain English to increase web accessibility,” in *Proceedings - 3rd International Workshop on Web Site Evolution, WSE 2001*, 2001, vol. 1, pp. 42–48, doi: 10.1109/WSE.2001.988784.

[26] T. Kluyver *et al.*, “Jupyter Notebooks-a publishing format for reproducible computational workflows.,” in *Positioning and Power in Academic Publishing: Players, Agents and Agendas - Proceedings of the 20th International Conference on Electronic Publishing, ELPUB 2016*, 2016, pp. 87–90.

[27] M. A. Marco Buzunariz, “Web Based Notebooks for Teaching, an Experience at Universidad de Zaragoza,” in *International Congress on Mathematical Software*, 2020, pp. 386–392, doi: 10.1007/978-3-030-52200-1_38.

[28] D. H. Smith, Q. Hao, C. D. Hundhausen, F. Jagodzinski, J. Myers-Dean, and K. Jaeger, “Towards Modeling Student Engagement with Interactive Computing Textbooks: An Empirical Study,” *SIGCSE 2021 - Proc. 52nd ACM Tech. Symp. Comput. Sci. Educ.*, pp. 914–920, 2021, doi: 10.1145/3408877.3432361.

[29] J. Reades, “Teaching on jupyter – using notebooks to accelerate learning and curriculum development,” *Region*, vol. 7, no. 1, pp. 21–34, 2020, doi: 10.18335/region.v7i1.282.

[30] J. W. Johnson, "Benefits and Pitfalls of Jupyter Notebooks in the Classroom," *SIGITE 2020 - Proc. 21st Annu. Conf. Inf. Technol. Educ.*, pp. 32–37, 2020, doi: 10.1145/3368308.3415397.

[31] N. Hara, "Student Distress in a Web-based Distance Education Course," *J. Int. Inf. Manag.*, vol. 10, no. 1, pp. 57–73, Jan. 2001, doi: 10.1080/13691180010002297.

[32] L. Stoel and K. H. Lee, "Modeling the effect of experience on student acceptance of Web-based courseware," *Internet Res.*, vol. 13, no. 5, pp. 364–374, 2003, doi: 10.1108/10662240310501649.

[33] H. F. Lin, "An application of fuzzy AHP for evaluating course website quality," *Comput. Educ.*, vol. 54, no. 4, pp. 877–888, 2010, doi: 10.1016/j.compedu.2009.09.017.

[34] W. C. Chiou, C. C. Lin, and C. Perng, "A strategic framework for website evaluation based on a review of the literature from 1995-2006," *Inf. Manag.*, vol. 47, no. 5–6, pp. 282–290, 2010, doi: 10.1016/j.im.2010.06.002.

[35] C. Weng, S. Otanga, A. Weng, and J. Cox, "Effects of interactivity in E-textbooks on 7th graders science learning and cognitive load," *Comput. Educ.*, vol. 120, no. February, pp. 172–184, 2018, doi: 10.1016/j.compedu.2018.02.008.

[36] A. Bacher-Hicks, J. Goodman, and C. Mulhern, "Inequality in household adaptation to schooling shocks: Covid-induced online learning engagement in real time," *J. Public Econ.*, vol. 193, p. 104345, 2021, doi: 10.1016/j.jpubeco.2020.104345.

[37] C. S. Fichten *et al.*, "Disabilities and e-Learning Problems and Solutions: An Exploratory Study," *J. Educ. Technol. Soc.*, vol. 12, no. 4, pp. 241–256, 2009.

[38] F. P. B. Mota and I. Cilento, "Competence for internet use: Integrating knowledge, skills, and attitudes," *Comput. Educ. Open*, vol. 1, no. July, p. 100015, 2020, doi: 10.1016/j.caeo.2020.100015.

[39] N. Johnston and N. Ferguson, "University Students' Engagement with Textbooks in Print and E-book Formats," *Tech. Serv. Q.*, vol. 37, no. 1, pp. 24–43, 2020, doi: 10.1080/07317131.2019.1691760.

[40] P. M. Wood and V. Bhute, "Exploring Student Perception toward Online Homework and Comparison with Paper Homework in an Introductory Probability Course.," *J. Coll. Sci. Teach.*, vol. 48, no. 5, pp. 68–75, 2019.

[41] E. E. Scott, M. P. Wenderoth, and J. H. Doherty, "Design-based research: A methodology to extend and enrich biology education research," *CBE Life Sci. Educ.*, vol. 19, no. 3, pp. 1–12, Sep. 2020, doi: 10.1187/CBE.19-11-0245/ASSET/IMAGES/LARGE/CBE-19-ES11-G004.JPEG.

[42] "Font Size Guidelines for Responsive Websites (2021 Update)." [Online]. Available: https://www.learnui.design/blog/mobile-desktop-website-font-size-guidelines.html. [Accessed: 04-Aug-2022].

[43] "Colors with Good Contrast | Web Accessibility Initiative (WAI) | W3C." [Online]. Available: https://www.w3.org/WAI/perspective-videos/contrast/. [Accessed: 04-Aug-2022].

[44] H. Harvey and R. Walker, "Reading comprehension and its relationship with working

memory capacity when reading horizontally scrolling text," *Q. J. Exp. Psychol.*, vol. 71, no. 9, pp. 1887–1897, Jan. 2018, doi: 10.1080/17470218.2017.1363258.

[45] "hypothesis.is." [Online]. Available: https://web.hypothes.is/. [Accessed: 25-Apr-2020].

[46] A. K. Ellis and J. B. Bond, "The Flipped Classroom," *Res. Educ. Innov.*, pp. 163–168, 2018, doi: 10.4324/9781315617145-21.

[47] C. Stöhr, C. Demazière, and T. Adawi, "The polarizing effect of the online flipped classroom," *Comput. Educ.*, vol. 147, no. September 2019, 2020, doi: 10.1016/j.compedu.2019.103789.

[48] P. Strelan, A. Osborn, and E. Palmer, "The flipped classroom: A meta-analysis of effects on student performance across disciplines and education levels," *Educ. Res. Rev.*, vol. 30, no. January, p. 100314, 2020, doi: 10.1016/j.edurev.2020.100314.

[49] Y. Y. J. Koh, J. I. Rotgans, P. Rajalingam, P. Gagnon, N. Low-Beer, and H. G. Schmidt, "Effects of graded versus ungraded individual readiness assurance scores in team-based learning: a quasi-experimental study," *Adv. Heal. Sci. Educ.*, vol. 24, no. 3, pp. 477–488, 2019, doi: 10.1007/s10459-019-09878-5.

[50] M. Poldaas, "Print or Electronic? Estonian Students' Preferences in Their Academic Readings," in *Information Literacy: Key to an Inclusive Society. ECIL 2016. Communications in Computer and Information Science*, 2016, doi: 10.1007/978-3-319-52162-6_23.

[51] J. M. Lodge and L. Corrin, "What data and analytics can and do say about effective learning," *npj Sci. Learn.*, vol. 2, no. 1, p. 1, 2017, doi: 10.1038/s41539-017-0006-5.

[52] I. S. Domazet and V. M. Simovic, "The Use of Google Analytics for Measuring Website Performance of Non-Formal Education Institution," in *Handbook of Research on Social and Organizational Dynamics in the Digital Era*, IGI Global, 2020, pp. 483–498.