Now what? Pedagogical implications of a shift to open book assessment of vector calculus

Tracy S. Craig
Department of Applied Mathematics
University of Twente
Enschede, the Netherlands
t.s.craig@utwente.nl

Fulya Kula
Department of Applied Mathematics
University of Twente
Enschede, the Netherlands
f.kula@utwente.nl

Tugce Akkaya
Department of Applied Mathematics
University of Twente
Enschede, the Netherlands
t.akkaya@utwente.nl

2022 IEEE Global Engineering Education Conference (EDUCON) | 978-1-6654-4434-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/EDUCON52537.2022.9766568

***Abstract*—During the global pandemic, a drastic change in higher-level education took place in assessment. The traditional closed book format had to evolve to a technology-mediated open book assessment for engineering students in a vector calculus course. It became evident that the traditional format was no longer in line with the modern world both functionally and didactically. Such change in the assessment places a responsibility upon us as teachers for constructive alignment of the teaching and learning environment. In this paper, we identify four categories of pedagogical implications and conclude with concrete suggestions for classroom practice.**

Keywords—* *open book assessment, vector calculus, technology-mediated assessment, engineering education

I. Introduction

In a vector calculus course taught at our institution by two of the authors, we have made the shift to technology-mediated open book assessment. This shift from traditional closed book examinations was forced upon us by the global pandemic. The traditional format of the assessment was not appropriate for open book assessment. This change resulted in the search for the type of questions that are not straightforward and cannot be searched online or in the book at the moment of the assessment. We have recognised the advantages of this particular form of assessment from both the assessment point of view and that of the student's learning gains. Therefore, we plan to continue with a modified form of open book assessment going forward.

Mathematics assessment, generally speaking, is closed book, written under controlled circumstances, often with no calculator [1], [2], [3], [4], [5]. A slight deviation from fully closed book is to allow students to create their own formula sheets (see for example [6]). The direct opposite of fully closed book is "open book, open internet" [7] also called "OBOW - open book open web" [4], [8]. The mode of assessment we are considering in this paper has been called technology-mediated open book assessment [9] and involves controlled access to chosen resources including technological resources.

[4] present examples of a wide variety of changes to teaching and learning environments related to the educational potential of technology and the internet. However, they add "one aspect of university life has barely changed at all; namely, the end-of-semester examination. Indeed, the final examination is a university institution that would appear to be off-limits as far as innovation is concerned." [4: 397] They argue that pen and paper examinations are not only an anachronism but are inconsistent with modern learning theory. [8] agree that IT-free examinations "are becoming increasingly artificial and unrealistic" [8: 2] given that we are preparing students for occupations where access to internet resources and software tools will be ubiquitous.

Arguments in favour of open book testing in mathematics include that it allows for more opportunities for assessing higher-order thinking skills [10]. [3] agree, suggesting that the primary advantage of open book over closed book assessment is, when designed effectively, "they can encourage students to engage with the assessment task in a more critical and analytical way, furthering the development of higher-order cognitive skills and assessing conceptual understanding." [3: 3] Additional advantages to open book assessment, beyond the scope of our discussion here, include the development of information literacy skills [3] and reducing exam anxiety [11].

In counterargument, some have argued that well designed closed book exams already do rise to the challenge of assessing higher-order skills [12] and [13] find that open book exams diminish long-term learning and encourage academic behaviour associated with "lower levels of academic achievement" [10].

A shift from traditional closed book assessment to technology-mediated open book assessment should ideally be carried out with care (and hence not with two weeks' notice during a global pandemic, for instance). Many have pointed out the different sort of preparation that is required for an open book test [10], [11] and the potential pitfall of students thinking very little preparation is needed [3].

We ask: "what are the pedagogical implications of a change from closed book to technology-mediated open book testing in vector calculus"? We conclude that there are 4 implications (or clusters of implications) which we term

- Alignment of question expectation
- Development of skill set
- Work habits
- Equity

First, we describe the context of the course and the impetus to make the shift to technology-mediated open book testing. We follow with a brief discussion of the four implications for teaching and learning which we have identified. Finally, we present practical suggestions for classroom practice to better align the educational environment with the expectations of the assessment.

II. Context

The content of the vector calculus course includes double, surface, triple and line integrals, vector fields and the fundamental theorem for line integrals, Green's, Stokes' and Gauss's Theorems, and covers applications such as area, volume, mass, work, circulation and flux. The class size is usually approximately 150 students and includes students from two programmes, which are Advanced Technology and Electrical Engineering at the University of Twente. The course is taught over six weeks (six contact hours per week) and is assessed with a two-hour examination in week 7. There is a second chance (termed a "resit") in week 10. The course begins in February and the first exam is towards the end of March.

Prior to the 2019-2020 academic year the two-hour exam was a traditional closed book exam written under controlled circumstances. In March 2020, at the end of week 5 of the academic quarter (and hence two weeks before the exam was due to be written) our institution, as many, shut down on-campus activities and our vector calculus exam could not be run in a traditional manner. We made an abrupt change to an open book and open internet exam to be written at home, non-proctored and to be completed within a limited time. We have written about this experience elsewhere [7], [14] where we observed that multivariable and vector calculus lends itself quite comfortably to open book assessment. We have since attempted to design open book assessment for our more elementary single variable calculus courses and have found this task a great deal more challenging. In the academic year 2020-2021, with more time to prepare, we distilled certain design principles for open book vector calculus assessment [14], chief amongst which is the necessity for decision making on the part of the student taking the exam [7]. Others [4], [8] support this observation, that a strength of well-designed open book assessment is positioning the student as a decision maker.

While in the previous two years the "write at home" nature of the assessment required unrestricted open book and open internet access, in the current academic year of 2021-2022 we shall return to writing the exam under controlled circumstances. To bring the advantages of the open book environment into the assessment this year we shall be using the e-assessment capacity of our institution in the form of Chromebooks. [8] consider two different infrastructure options for open book exams requiring access to technology, these are (i) using the university's computers, or (ii) students bringing their own device. They find there are strengths and weaknesses to the two options. While using the university's computers gives students an identical assessment experience (unlike students using their own comfortably familiar but highly variable devices) a disadvantage is that the university needs large computer rooms. Our institution avoids that disadvantage by having large banks of Chromebooks that can be relocated to several different venues. In the exam venue, each student will have access to a Chromebook on which they can access certain chosen lecture notes and white-listed online tools in a virtual machine environment. The online tools are GeoGebra, a powerful graphing application including manipulable 3d-graphing of surfaces and space curves, and Symbolab, a versatile online calculator. Furthermore, students can bring in a formula sheet they have created for themselves. It has been found that students learn best and enjoy the most when they are tested closed book with "handwritten note cards" as compared to either fully open book or closed book exams [11]. We shall be allowing handwritten formula sheets as well as lecturer-supplied course notes. An option for the future, suggested by [11], would be to only allow formula sheets.

III. Pedagogical Implications of the Shift to Open Book Assessment

A. Alignment of question expectation

The design principles [14] we are using for setting a vector calculus exam paper are: encourage decision making, create opportunities for noticing available options, provide diagrams, low emphasis on solving integrals, and avoid formats with familiar forms. Chief amongst these is decision making through information interpretation [7].

The majority of exercises in the textbook, questions from old exam papers, and exercises we have set as in-class activities are unsuitable for open book exams using these design principles. Ways in which they are unsuitable include

- Stating the method to be used (for example Green's Theorem) which undermines the first two design principles
- Requiring lengthy solving of an integral
- Too great a degree of prompting, for instance asking for the curl of a vector field before requiring the line integral of a (conservative) vector field
- Making the focus of the question something that is purely computational, such as determining a Jacobian.
- Asking straightforward questions, which can be easily answered on online tool exercises, such as line integrals of vector fields for work, circulation and flux.

Many students choose to work through old exams as a good way to study for an upcoming one. From our experience, this study technique also leads the students to memorize the solution pattern and to have in-depth knowledge only on how to solve these particular questions. In order to assess their higher order learning skills, such as how and why to solve these types of questions, the form of assessment should be redesigned to require their decision making skills. Changing the form of assessment in a way that changes the type of question being asked, as we discuss here, poses a serious danger to students' exam preparation.

As their teachers, we incur a responsibility to help the students avoid the pitfall of using old, poorly aligned exams as their primary study source. We need to not only align in-class resources, such as tutorial worksheets, with the upcoming exam but also explicitly problematize poorly aligned old exams in a way that students will notice and understand.

B. Skills development

At the time of writing the students who will be taking the vector calculus course this year are in the first author's Calculus 2 class. A poll was carried out to determine the students' perception of their own skill levels in using one example of a popular 3d graphing package and one example of a powerful online calculator. In Table 1, results show that a majority (79%) of the students consider themselves beginners at using the 3d graphing software and an even larger majority (91%) as beginners at using the chosen online calculator.

TABLE I. PROFICIENCY IN THE USE OF ONLINE TOOLS

Online tools	Proficiency in the use of online tools			
	Beginner (f,%)	***Intermediate (f,%)***	***Advanced (f,%)***	***Total response***
Proficiency in GeoGebra	92, 79%	22, 18%	1, 1%	113
Proficiency in Symbolab	103, 91%	7, 6%	3, 2%	116

Neither of these tools can be used effectively without practice. Relevant competence with any graphing software includes knowing how to navigate to the 3d graphing window, enter equations of surfaces, indicate intersections of surfaces, tip and rotate the view, and so forth. Facility with online calculators includes knowing how to find suitable mathematical structures from the menu available and how to use those properly. These tools will be made available during the exam in order to help students visualise objects in 3d-space and to shift the emphasis of the exercises away from computation and towards setting up integrals. For example, to determine the volume of a solid the student has to set up a triple integral with suitable bounds, possibly employing a change of coordinate system. From the point of view of the assessor, in this example, it is important that the student show the first few steps of the computation in order to display their proficiency at executing the coordinate change, yet thereafter the computation is of little interest. Here is where a powerful calculator can be used, yet if the student is inexperienced at using it then the advantage of the time saved is lost. Through anecdotal evidence, we are aware that in the preceding two years, when any tool on the internet was available for the students to use in their written at home exams many did not use them.

In our experience, many students struggle with visualising and drawing objects in 3-dimensional space. In a vector calculus course we encounter surfaces such as spheres, paraboloids, planes and so forth as well as space curves such as lines, helices, twisted cubics and intersections of surfaces. Direction and orientation are frequently important, such as in flux exercises where we work with oriented surface integrals. In exercises utilising Stokes' Theorem one oriented surface can be replaced by another as long the directionality of the shared boundary curve is maintained. 3-d computer graphing packages can assist the student significantly in understanding how surfaces and curves look and how they interact with one another. [15] suggests even deeper immersion into the 3d visual experience using virtual reality functionality for direct manipulation of room-sized geometric objects.

C. *Work habits*

Research shows that students do not prepare well for open book tests without guidance. [16] agrees that students need more guidance on how to prepare themselves for open book tests especially if the students experience more traditional closed book tests during their study. [10] and [11] observe that preparing for a closed book exam is different to preparing for an open book exam and students often do not prepare enough or properly for this type of exam. [5], in their literature review of open book assessment, cite several examples of inappropriate preparation.

Students exhibit a tendency to rely too much on the availability of the resources, in our case lecturer-supplied course notes, and to waste time looking things up. For example, in studying for a closed book exam a well-prepared student would learn how to shift from Cartesian coordinates to spherical coordinates, or how to determine if a vector field is conservative, but might relegate that knowledge to "looking up" in an open book exam, to the detriment of their time management.

Open book exams provide the opportunity to assess higher-order skills by designing questions that rely less on memory or computation and more on decision making, applying skills, and making connections. [3], [7] and [17] provide suggestions and examples of how to change traditional closed book exam questions to be better suited to an open book context. It will frequently be the case that these new open book exam questions are more challenging for students and hence require more preparation than a closed book exam might require. We have a responsibility to make students aware of the difference in the preparation required and to provide opportunities for the development of suitable work habits.

D. *Equity*

Having turned to remote assessment with open book examinations, we recognise its strengths and on the other hand, we acknowledge the factors affecting equity require careful consideration. It is indicated that the imperative shift to digital instruction privileged some students and pressurized others with no access to the right resources [18]. In a technology-mediated open book assessment setting, equity needs to focus on developing environments and systems in ways to provide students with what they need to comfortably use the technological tools. In this manner, better sources are necessary to use our assessments that support equity as opposed to standardization. This idea of not standardization is one of the drives to continue the use of open book assessment.

Supporting equity is one of the drives to continue the use of open book assessment complemented by technology. However, we teachers need to adjust our practice to respond to and meet the needs of students in terms of the use of technology. We observe only a few students are skilled at using the chosen 3d graphing software and online calculator (see Table 1). Considering their proficiency in these tools, the assessment will stay inequitable. We look for ways to support all students by providing ways to develop these skills while the course takes place.

The fairness of technology-mediated open book assessment is also likely to be affected by the resources available to students, academic and otherwise. Preparation for these examinations is dependent on a satisfactory use of the available software. While it is usually possible to use any device with an internet connection for this preparation, the abilities and comfort of use might vary between devices and the bandwidth. Moreover, access to laptops might stay as another barrier to the equitable preparation of these exams. It should not be assumed that all students are afforded equitable learning opportunities [19], financially disadvantaged students may have limited access to such resources during the exam preparation.

The other factors potentially impacting equity in this kind of assessment might be the prior mathematics knowledge, learning difficulties, working habits, communication preferences, and gender-specific issues. While the gender disparities in favour of males have been a consistent fact in mathematics for more than three decades [20], [21], it is also evident that males are advantaged over females while using the technology in high stakes examinations [22]. To overcome such inequity cases, we provide extra learning opportunities, pencasts that are helpful for the students with impairments. The study advisors work closely with students which helps a great deal in many aspects, including psychosocial. For different communication styles in our teaching, we provide both synchronous in-class communication opportunities and also mostly textual asynchronous opportunities.

IV. CONCRETE SUGGESTIONS

To address the alignment of students' expectations of what exam questions to expect we have two responsibilities with respect to course resources. The first is related to sample exam papers and the second to in-class activities. Students study for exams at least in part by working through old exam papers but also learn the course content continuously throughout the course by engaging with in-class activities, worksheets, chosen textbook exercises, quizzes and so forth.

A first and obvious action should be to make the exam papers for the past two years available for students to work through. The 2021 exam paper is particularly well-aligned with our forthcoming expectations of the 2022 exam since we were better prepared by that time, unlike in March 2020. A second action should be to take some older exams and make explicit which questions are good examples of what they might expect to see now, which are poor examples, and why. Our experience informs us that these annotations should be unavoidable (that is, written on the downloadable old exam paper itself) rather than in a separate document as that can easily be missed. An example of a question that is poorly suited to an exam where access to a powerful calculator is available is shown in Figure 1. The integral requires a change of order of integration, however, an online calculator will carry this change out automatically without any awareness of the need to do so on the part of the student.

Evaluate the double integral below.
Include a diagram in your answer.

$$\int_0^4 \int_{\sqrt{y}}^2 \sin(x^3)\, dx\, dy$$

Fig. 1. Traditional question poorly aligned with the new method of assessment

A possible option, yet to be explored, is to have the students themselves design exam questions according to the design principles. If a sizable bank of such problems exists then we could draw on those questions for the actual test. Others (see for example [23]) have found that student generation of exam questions increases engagement and motivation.

The existing resources we draw on for in-class engagement include exercises we have drawn up ourselves over the years as well as exercises assigned from the standard course textbook. A serious drawback of the textbook for preparation for an open book exam is that the solutions are all available online. Even if we assign exercises that are excellently aligned with our exam question expectations, our experience shows that students rapidly look to the solutions for tips on how to proceed rather than applying any sort of problem solving behaviour themselves. This propensity makes textbook use a poor means of preparing for the types of questions the students will see in their open book exam.

The University of Twente bachelor programmes are grounded in project-based learning, each programme consisting of a series of thematic modules composed of a cluster of courses surrounding a project [24]. Ideally the courses are closely related to the project encouraging motivation to learn and to engage. This model is effectively a form of enquiry-based learning (EBL) which is understood to support the development of life-long learning skills and allows engagement with course material at a deeper level than traditional teaching and learning methods [25]. While the module itself is run within this framework the individual courses are often not. Traditional teaching of mathematics is particularly prone to a didactic mode in conflict with EBL. Given that a redesign of the course materials (such as tutorial exercises) is unavoidable if we are to align them with open book exam expectations [16] we are considering doing so within an EBL framework.

Existing teaching and learning resources are our weekly quizzes, completed by the students when they feel ready to take them. The questions are multiple choice and are deliberately designed to be non-computational so as to not be vulnerable to careless error. Instead, the questions are designed to test understanding of the fundamental concepts. Our experience designing those quiz questions was drawn on when designing our initial open book exams. An example of such a quiz question is shown in Figure 2. A variation on this quiz question was included in the 2021 exam [7] since we understood it to adhere to our design principle of decision making through information interpretation. Note that Figure 2 shows a multiple choice quiz question. The version of the question included in the exam required motivation for the answer.

Question 2 1 pts

A textbook exercise says "Find the work done by the field **F** along the boundary of S where S is that part of the paraboloid $z = 10 - x^2 - y^2$ which lies above $z = 1$."

We shall use Stokes' Theorem to solve the problem and will use the formula

$\int_C \mathbf{F} \cdot d\mathbf{r} = \iint_S \nabla \times \mathbf{F} \cdot d\mathbf{S}$

Which of the following is an *incorrect* choice for S?

- $x^2 + y^2 + z = 10, \quad z \geq 1$
- $x^2 + y^2 = 9, \quad z \geq 1$
- $z = 1, \quad x^2 + y^2 \leq 9$
- $x^2 + y^2 + z^2 = 10, \quad z \geq 1$

Fig. 2. Quiz question from week 6 requires decision making and processing information

Another example of an exam question that requires the student to interpret the information given and make decisions on how best to proceed is shown in Figure 3. The student needs to know that, using Green's Theorem, area can be determined by means of a line integral, needs to be able to find the limits of integration and what they represent, and finally needs to understand what area they'll be calculating and how it relates to the region R described.

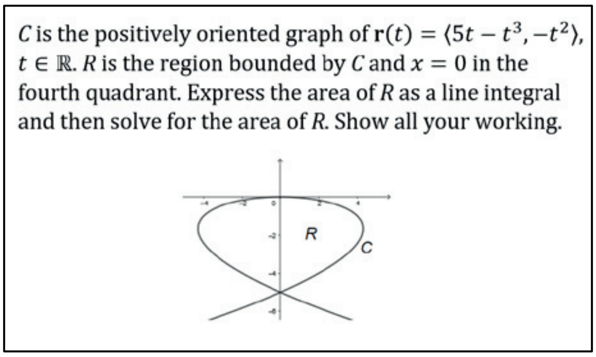

Fig. 3. Exam question requiring information interpretation and decision making

If the tools made available to the students in the exam venue are to be of any assistance then the students need to develop the skills of using them. We could choose to encourage the students to develop these skills in their own time, however, it is more pedagogically sound and more ethical to provide students with in-class opportunities to develop the necessary skills.

We have six contact hours with the students each week, two hours of lectures and four hours of tutorial or workshop time when the students have the opportunity to engage with the concepts of that week. Traditionally the tutorial exercises are expected to be completed without the use of any tools other than a pencil, however, this expectation needs to change if we wish to support students' development of the new skill set. The only existing exception to this requirement to solve using pencil and paper is our institution's use of Grasple, which is an online mathematics e-learning platform with significant functionality. As an online learning environment, the Grasple company is used mainly for homework exercises and diagnostic tests for the service mathematics courses at our institution as well as other Dutch Technical Universities.

On Grasple, students are still expected to solve the exercises by hand and then to enter results into the digital system for checking and feedback. Approximately one quarter of our students use the Grasple platform actively. We shall intensify our encouragement of students using this since not only is this e-learning platform beneficial for learning generally it is also useful for developing skills of typing mathematical text.

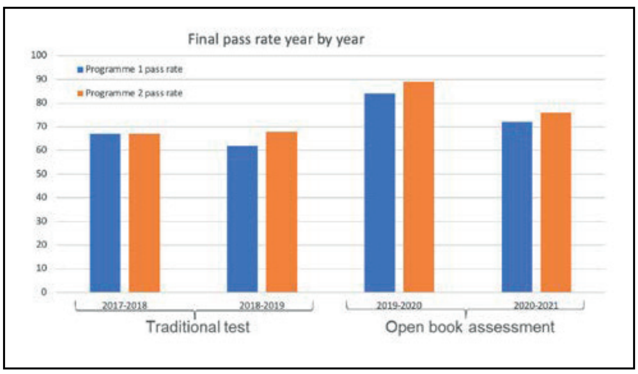

Fig. 4. Pass rates before and after change of assessment mode

Figure 4 presents data related to the pass rates of students (out of 100) of the last two years' results of the open book assessment, open internet exams, concerning the two programmes taking the course. The two of the authors have been the teachers throughout the mentioned four years. To give an idea to the reader about the student experience in terms of achievement, we would like to stress the improvement of the pass rate in the last two years with the open book assessment, despite the novelty of examination mode. Even though there seems to be a trend down in the pass rates during 2020-2021, it is notably higher than the traditional exam results.

To address development of the skill sets of manipulation of 3d graphing software and use of calculators we plan to design tutorial exercises that focus exclusively on the use of these tools or include integrals very challenging to solve by hand. For example, an exercise could ask for a description of the shape of the curve of intersection of two surfaces, or an integral could use a technique we do not include in our curriculum such as decomposition into partial fractions. Furthermore, we are exploring options for the students already proficient in the use of these powerful tools to contribute to the development of their fellow students' skills, or to share examples of their own work. An example of the latter has already been incorporated in one of our courses in which a platform has been provided in our learning management system for students to share resources, some of their own making [26]. In Figure 5 we show a screenshot from a student-made video of a revolving viewpoint of a dynamic twisted cubic. The student, who had considerable skill in using GeoGebra, created the video for the benefit of his fellow students who were struggling to picture the curve.

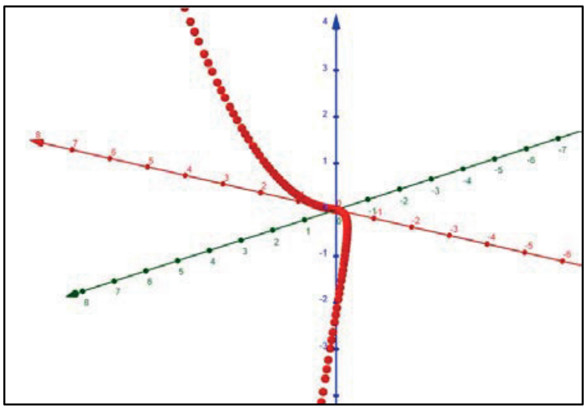

Fig. 5. Screenshot of video of dynamic twisted cubic plot

Finally, discussion with the e-learning platform Grasple suggests that 3d graphing software and online calculators can be embedded in their system to further support a productive learning environment.

Others have observed that preparation for an open book (particularly technology-mediated open book) exam requires different preparation to that for a closed book exam. There is the danger that students could rely too much on the possibility of looking things up. In addition to being straightforward and explicit in class about the need for appropriate preparation, for instance stressing that there will be little time for looking everything up, we shall create an opportunity for students to experience what the exam will be like in a low-stakes context, as recommended by [3]. The current schedule of each of our courses includes a two-hour session shortly before the exam for “Q&A”. Typically these sessions are general opportunities for students to ask questions, or they are used for the teacher to work through an old exam paper with explanations. An option we are considering is using that session to mimic exam conditions, provide the students with a sample exam similar in form to the upcoming open book exam, and encourage the use of the resources which will be available. In this simulated exam, the students would probably have to make use of their own devices although we shall discuss the option of using the institutional Chromebooks with our e-learning team.

Finally, we shall attempt to ensure that every student has the technological capacity and infrastructure to practise using the software tools by drawing on the facilities and support services of our institution

V. Conclusion

Our shift from closed book to open book (and then open internet) assessment was uninvited, forced upon us by global circumstances. Driven by recognition of the benefits of open book assessment and the benefit of certain types of software tools in vector calculus specifically we shall continue with open book assessment. In our case, we are defining our technology-mediated open book assessment as including course notes, student-created formula sheets, access to 3d graphing software and access to a powerful online calculator.

Such a shift has pedagogical implications in order to ensure alignment and preparation. We identify four (clusters of) implications which are: alignment of question expectation, development of skill set, work habits and equity. We as teachers, having implemented this shift in assessment form, have incurred a responsibility to address these concerns.

In the past year, great attention has necessarily been paid to changes in the teaching and learning environment as much teaching has moved online and significant changes have been imposed on assessment. Our work on technology-mediated open book assessment in vector calculus contributes to the active and ongoing conversation in the educational literature, particularly that part of it dedicated to STEM education.

References

[1] P. Iannone, "Assessing mathematics at university: Covid-and beyond," *Newsletter of the London Mathematical Society,* vol. 490, pp. 34–40, 2020.

[2] S. Trenholm, "An investigation of assessment in fully asynchronous online math courses," *International Journal for Educational Integrity,* vol. 3, no. 2, pp. 41-55, 2007. [Online]. Available: https://doi.org/10.21913/IJEI.v3i2.165.

[3] J. Johnston and P. Rooney. "Open-Book Assessment: A handbook for academics." Trinity College. http://www.tara.tcd.ie/handle/2262/95650 (accessed December, 2021).

[4] K. Mohanna and A. Patel, "Overview of open book-open web exam over blackboard under e-Learning system," presented at the Fifth International Conference on e-Learning (econf). IEEE, 2015.

[5] A. M. Parker, E. Watson, N. Dyck, and J. P. Carey, "Traditional Versus Open-Book Exams in Remote Course Delivery: A Narrative Review of the Literature," in *Canadian Engineering Education Association (CEEA-ACEG) Conference* 2021, no. June 20 - 23 PEI doi: https://doi.org/10.24908/pceea.vi0.14845.

[6] B. Loch and A. Edwards, "A preliminary categorization of what mathematics undergraduate students include on exam crib sheets'," presented at the The 18th SIGMAA Conference on Research in Undergraduate Mathematics Education (RUME 2015), Pittsburgh, PA, USA, 19-21 February 2015, 2015.

[7] T. S. Craig and T. Akkaya, "Forced to improve: open book and open internet assessment in vector calculus," *International Journal of Mathematical Education in Science and Technology,* pp. 1-8, 2021, doi: 10.1080/0020739X.2021.1977403.

[8] L. Moccozet, O. Benkacem, C. Tardy, E. Berisha, R. T. Trindade, and P. Y. Bïrgi, "A versatile and flexible framework for e-assessment in Higher-Education," presented at the 17th International Conference on Information Technology Based Higher Education and Training (ITHET), IEEE, 2018.

[9] T. Piyatamrong, J. Derrick, and A. Nyamapfene, "Technology-Mediated Higher Education Provision during the COVID-19 Pandemic: A Qualitative Assessment of Engineering Student Experiences and Sentiments," *Journal of Engineering Education Transformations 34.SP ICTIEE,* pp. 290-297, 2021.

[10] A. J. Swart and T. Sutherland, "Student Perspectives of Open Book versus Closed Book Examinations a Case Study in Satellite Communication," *International Journal of Engineering Education,* vol. 30, pp. 210-217, 2014.

[11] R. M. Block, "A Discussion of the Effect of Open-book and Closed-book Exams on Student Achievement in an Introductory Statistics Course," *PRIMUS,* vol. 22, no. 3, pp. 228-238, 2012/04/01 2021, doi: 10.1080/10511970.2011.565402.

[12] R. N. Khan, "Assessments: an open and closed case," *International Journal of Mathematical Education in Science and Technology,* vol. 46, no. 7, pp. 1061-1074, 2015/10/03 2015, doi: 10.1080/0020739X.2015.1076534.

[13] R. Moore and P. A. Jensen, "Do Open-Book Exams Impede Long-Term Learning in Introductory Biology Courses?," *The Journal of College Science Teaching,* vol. 36, pp. 46-49, 2007.

[14] T. S. Craig, "Open book vector calculus assessment: suggested design principles," in *49th SEFI Conference*, 2021, pp. 1365-1369.

[15] M. Takac, "Application of Web-based Immersive Virtual Reality in Mathematics Education," presented at the 21th International Carpathian Control Conference (ICCC). IEEE, 2020

[16] V. Msila, "Open Book Examinations in a Distance (Teacher) Education Programme: South African Teacher-learners' Experiences," *International Journal of Distance Education Technologies (IJDET),* vol. 9, no. 3, pp. 1-12, 2011, doi: http://doi.org.ezproxy2.utwente.nl/10.4018/jdet.2011070101.

[17] T. Bailey, G. Kinnear, C. Sangwin, and S. O'Hagan, "Modifying closed-book exams for use as open-book exams," *OSF Preprint,* 2020. [Online]. Available: https://doi.org/10.31219/osf.io/pvzb7

[18] T. N. Hohlfeld, A. D. Ritzhaupt, K. Dawson, and M. L. Wilson, "An examination of seven years of technology integration in Florida schools: Through the lens of the Levels of Digital Divide in Schools," *Computers & Education,* vol. 113, pp. 135-161, 2017/10 2017, doi: 10.1016/j.compedu.2017.05.017.

[19] A. T. Wilson, "Knowledge for Equitable Mathematics Teaching: The Case of Latino ELLs in U.S. Schools," *The Mathematics Enthusiast,* vol. 13, pp. 111-129, 2016.

[20] H. W. Marsh, "Sex Differences in the Development of Verbal and Mathematics Constructs: The High School and Beyond Study," *American Educational Research Journal,* vol. 26, no. 2, pp. 191-225, 1989, doi: 10.3102/00028312026002191.

[21] G. Hanna, *Towards Gender Equity in Mathematics Education*. Toronto, Canada: Kluwer Academic Publishers, 1996.

[22] H. J. Forgasz, S. Griffith, and H. Tan, "Gender, equity, teachers, students and technology use in secondary mathematics classrooms," in *17th ICMI Study Conference*, Hanoi, Vietnam, C. Hoyles, J. B. Lagrange, L. H. Son, and N. Sinclair, Eds., 2006: Hanoi University of Technology, pp. 1-8.

[23] P. Muñoz-Escalona, K. Savage, F. Conway, and A. McLaren, "Promoting undergraduate student engagement through self-generated exam activity," *International Journal of Mechanical Engineering Education,* vol. 46, no. 3, pp. 252-273, 2018, doi: 10.1177/0306419017743215.

[24] T. S. Craig, "The Twente Educational Model in theory and practice: Two modules as exemplars," in *Twelfth Southern Hemisphere Conference on the Teaching and Learning of Undergraduate Mathematics and Statistics* Perth, 24-29 November 2019 2019: Swan Delta.

[25] N. J. Powell *et al.*, "Four Case Studies of Adapting Enquiry-Based Learning (EBL) in Electrical and Electronic Engineering " *The International Journal of Electrical Engineering &*

Education, vol. 45, no. 2, pp. 121-130 2008. [Online]. Available: https://doi.org/10.7227/IJEEE.45.2.4.

[26] T. S. Craig, "Mapping knowledge networks," report of study undertaken for Senior University Teaching Qualification, 2021.