Oral Examinations in Environmental Engineering Design Courses

Prof. James N. Jensen, University at Buffalo

James N. Jensen is professor and chair of the Department of Engineering Education at the University at Buffalo. Dr. Jensen received a BS degree in environmental engineering from Caltech in 1980 and MSPH and PhD degrees from the University of North Carolina at Chapel Hill in 1983 and 1988, respectively. His research and teaching interests are in assessment, problem-based learning, and drinking water treatment in low-resource environments. He has received numerous teaching and research awards, including the Chancellor's Award for Excellence in Teaching and the President Emeritus and Mrs. Martin Meyerson Award for Distinguished Undergraduate Teaching and Mentoring.

Oral Examinations in Environmental Engineering Design Courses

ABSTRACT

Oral examinations allow for the assessment of oral communication, technical competency, and professionalism. They are known to promote high learning levels and increase student-faculty interactions. However, oral examinations may be difficult to scale and can suffer from subjectivity biases. An oral examination was implemented in a required drinking water and wastewater treatment plant design course. Student performance and survey responses were collected for 15 years. Responses to an open-ended question supported the idea that students performed at integrative learning levels during the oral exam. Over 78% of students reported that the oral exam would somewhat or definitely help them achieve their professional goals. Students indicated a slight preference to oral exams regarding the evaluation of their knowledge. The correlation of student performance across testing modalities is similar to the correlation of student performance across course material tested, although oral exams produced less student-to-student variability. Regarding equity, students reported that both written and oral exams were administered and graded fairly. There was no evidence of academic integrity issues due to the two- to three-day exam period. Over 85% of students reported that oral examinations were more suited to design courses rather than analysis courses. From the results of this study, it appears that oral examinations have a valuable role in engineering education, especially in design courses.

BACKGROUND

Roles of Oral Exams

Oral examinations serve two roles in engineering courses. First, oral examinations allow students to practice oral communication skills. Oral communication skills are important for engineers [1]. Seventy percent of practicing engineers in one survey identified oral communication in the workplace as important in job advancement [2]. As an indication of the importance of oral communication in environmental engineering, the American Association of Environmental Engineers requires an oral examination for recognition as a Board Certified Environmental Engineer. In addition, communication with a range of audiences is embedded in ABET Student Outcome 3.

Second, oral examinations serve as assessment tools. They are direct measures of student performance. Due to the importance of oral communication in the engineering profession discussed above, oral exams are a more authentic assessment for engineers than written exams [3].

While oral examinations are very common in continental Europe [4], they are less common in the United States and the United Kingdom especially in undergraduate engineering education. (Oral exams are common in the assessment of graduate work in thesis/dissertation defenses and qualifying examinations.) However, the use of oral examinations is being promoted worldwide for engineering in general [5], [6].

Benefits of Oral Exams

As assessment instruments, oral examinations have benefits over written exams. Oral examinations allow for the assessment of both oral communication and problem-solving skills [7]. Also, oral examinations uniquely provide an environment where follow-up questions can be asked [7], [8]. In this way, oral examinations probe the thought processes of the students [9], [5].

Oral examinations also have benefits over written examinations in terms of the impact on students. Students tend to respond at higher learning levels in oral examinations. Using the Structure of the Observed Learning Outcome (SOLO) taxonomy developed by Biggs and Collis [10], Olsson [11] found that chemical engineering students performed at more integrative levels during oral exams. This finding may be related to student preparation. Lundgren [12] found that students studying for an optional oral examination studied more and focused their study more on understanding the material. Oral exams also promote faculty-student interactions after the exams [13]. In computer science courses, East and Schafer [14] found that one-on-one grading experiences between students and faculty increased the general willingness of students to ask questions subsequent to the experiences. Regarind neurodiverse students, oral exams are typically conducted in a distraction-free, one-on-one environment. Finally, oral exams increase students' motivation to learn. In their study of 560 engineering students across six classes, Delson and colleagues [5] reported that 70% of survey respondents Strongly Agreed or Agreed that the oral exams increased their motivation to learn.

Challenges of Oral Exams

Oral examinations also have challenges. First, they must be given over a relatively long period of time. As a result, students may talk to one another and cheating is possible [15]. Second, they can be time-consuming to administer. Third, the grading of an oral examination may be more subjective than the grading of a written examination. Lundgren [12] quantified the variability of grading by having eight instructors grade eleven videotaped oral examinations on a scale of 0 to 5. The relative standard deviations (RSD) of the grades ranged from 16% to 43% (average RSD: 26%). Thomas and coworkers [16] studied oral examinations for final-year medical students and found poor agreement between both graders of videotaped oral examinations and graders of oral examination transcripts, suggesting that nonacademic factors influenced grading. Similarly, Coe and colleagues [9], using actors to read transcripts of oral examinations, found that the overall examination scores were influenced by the answer, presentation style, and how the "student" was dressed (in decreasing order of significance), but independent of gender. Fourth, oral exams may present as a high-pressure environment, especially to neurodiverse students.

METHODS

An oral examination has been given for 15 years in the course "CIE 442: Treatment Process Engineering" (2002-2010, 2012-2016, and 2022). The course is required in the BS environmental engineering program and satisfies a senior design technical elective for the BS civil engineering program. Characteristics of the students in the course over the study period are listed in Table 1.

The course typically had three examinations. Exam 1 covered design principles, design population, and drinking water treatment. Exam 2 covered drinking water distribution and wastewater collection, while the third exam covered wastewater treatment. During the study period, Exams 1 and 3 were offered only as written examinations. Exam 2 was offered as an oral exam. On nine occasions (2006, 2008-10, and 2012-16), the material on the second exam also was assessed through a short, written quiz given prior to the administration of the oral examination.

Table 1: Student Characteristics in CIE 442 over the Study Period

Characteristic	Number	Percentage
Total[1]	396	100.0%
Class		
Senior	340	85.9%
Junior	48	12.1%
Other	8	2.0%
Major		
Environmental engineering	245	61.9%
Civil engineering	133	33.6%
Chemical engineering	11	2.8%
Other	7	1.8%
Gender[2]		
Male	281	71.0%
Female	115	29.0%

Notes: 1. Average: 26/year
2. Data on gender identity were not collected. For all but the last year, student pronoun and gender identification data were not collected institutionally.

All examinations were weighted equally, with each contributing 15% of the final grade. The remaining 55% of the grade came from five design reports done as groups and short individual assignments related to the design reports. In a typical year, oral examinations were 20 minutes long and conducted over two to three days. All exams were given by the same instructor. Students signed up for a time slot. They were given background material on a county seeking a county-wide drinking water distribution system. In addition, students were asked to do a sanitary survey of part of the University at Buffalo's campus, in preparation for questions about wastewater collection on campus. Students were encouraged to collaborate in the exam preparation phase.

During the interactive, one-on-one examinations, students were asked to play the role of a consulting engineer, while the instructor played the role of a (non-technical) government official and a university facilities engineer. The student was allowed one page of notes to mimic a client

meeting. The instructor took notes on hidden grading sheets during the examination. The grading sheets contained potential questions and point values. In general, all students were asked the same questions. There was very minor variability in content which was judged by the instructor to be of equal difficulty. All students were asked questions that totaled a fixed number of points. If a student hesitated significantly during the examination or had to be prompted, then points were deducted. (The instructor accounted for perceived anxiety and spoken English difficulties in evaluating the hesitancy.) After all examinations were completed, the instructor distributed the grading sheets containing the instructor's notes, point values, and grades.

Students were surveyed anonymously at the end of the course regarding their opinions of the course examinations. Survey questions are listed in the appendix with the allowed responses (typically, a five-point Likert scale). The surveys had an 81% response rate (321 responses/396 total students).

RESULTS AND DISCUSSION

Learning

As discussed earlier, Olsson [11] found that chemical engineers performed at more integrative learning levels during oral exams. In the present study, there is evidence that students more integrative learning levels in the open-ended comments (emphasis added):

> "I felt that I had to know an equal amount of info for both types of exams, but had to ***concentrate on more than memorized info*** for the oral…"
>
> "made me ***realize my weak points and how to change***"
>
> "how I ***need to improve for the professional world***"
>
> "required me to ***think on my feet***"

The verb choices indicate higher learning levels in Bloom's revised taxonomy [17].

Professionalism

Students overwhelmingly responded that the oral exam would help them in their professional goals (Figure 1). Responses favoring oral exams were 20 times more frequent than responses favoring written exams with respect to professional goals (Written 3.9%, Same 17.7%, Oral 78.4%).

The open-ended comments supported the value of the oral exams for professionalism and oral communication skills. For example (emphasis added):

> "(The oral exam) tested in a ***more realistic way***"
>
> "***My intern project meetings were similar to the oral exam***."

"***Better practical use than written exams*** ... which are useless the day after the exam"

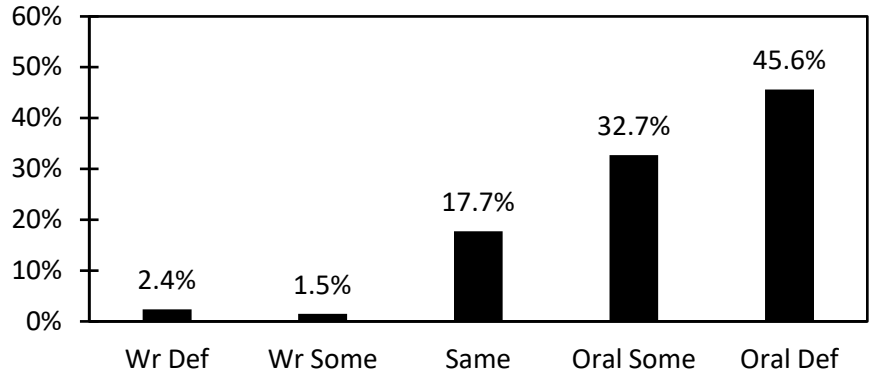

Figure 1: Survey Results for the Question "Which exam will help me in my professional goals?" (Wr = written exam, Def = definitely)

The strong connection to professionalism in the target course maybe have been due in part to the format of the exam. The exam was designed to mimic engineer-client interactions with two types of clients.

Oral Exams as Assessment Tools

Students indicated a slight preference to oral exams regarding the evaluation of their knowledge (Figure 2: Written 31.8%, Same 33.3%, Oral 34.9%). Open-ended comments indicated that some students acknowledged the flexibility of oral exams and their ability to promote communication skills:

"If oral exams were more popular in engineering, students would have ***better communication skills***."

"***can cover more ideas***" (with oral exams)

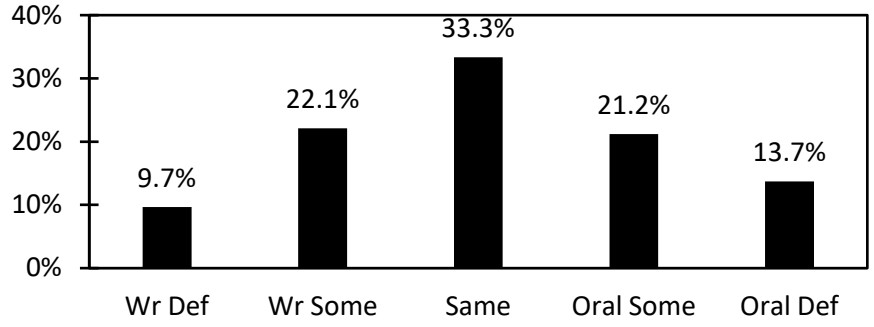

Figure 2: Survey Results for the Question "Which exam best evaluated my knowledge?"

It is of interest to examine whether the testing modality affects student performance. Plotted in Figure 3 are the correlation coefficients between the exams for the nine years in which a quiz over the oral exam material was administered. The leftmost three data sets (dashed box) represent different test topics with the same testing modality (written). The rightmost data set is the same test topics (distribution systems, collection systems) with different testing modalities.

It appears that the correlation of student performance across testing modalities is similar to the correlation of student performance across course material tested.

Equity

In the experiences reported here, oral exams were conducted as individualized interviews conducted over several days. As a result, it is important to consider whether the experience fairly represented the abilities of the students. There are three elements to equity here: perceived fairness, fairness to neurodiverse students, and academic integrity issues.

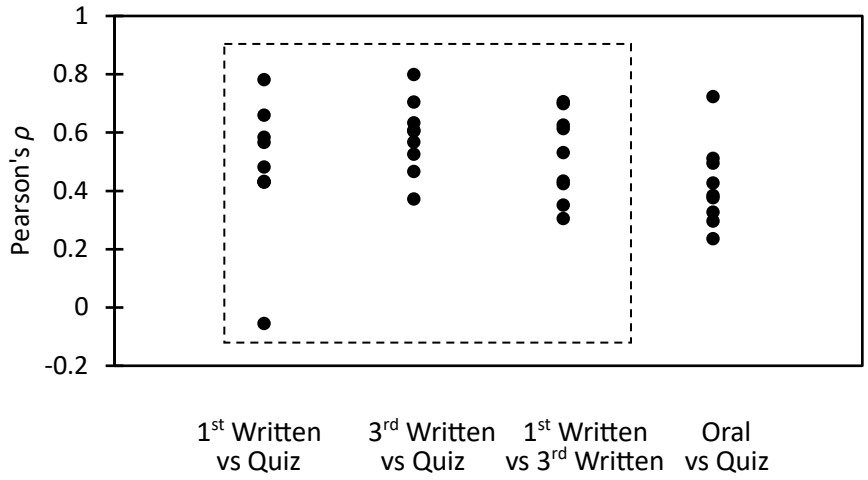

Figure 3: Correlations between Test Topics and Testing Modality

Perceived fairness. Overall, students reported the oral exam to be a fair experience. Regarding the fairness of exam administration (Figure 4), students reported little difference between the exam modalities (Written 16.8%, Same, 64.5%, Oral 18.7%). More students reported that they felt the written exam was graded fairer (Figure 5: Written 17.4%, Oral 12.9%), although 69.7% of respondents reported that the exam modalities were equally fairly graded.

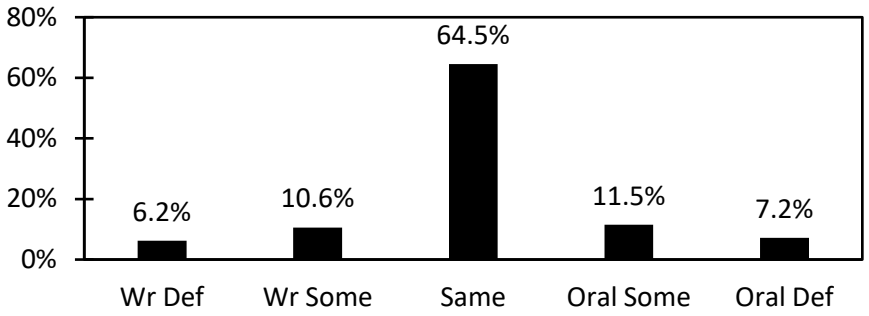

Figure 4: Survey Results for the Question "Which exam was administered fairest?"

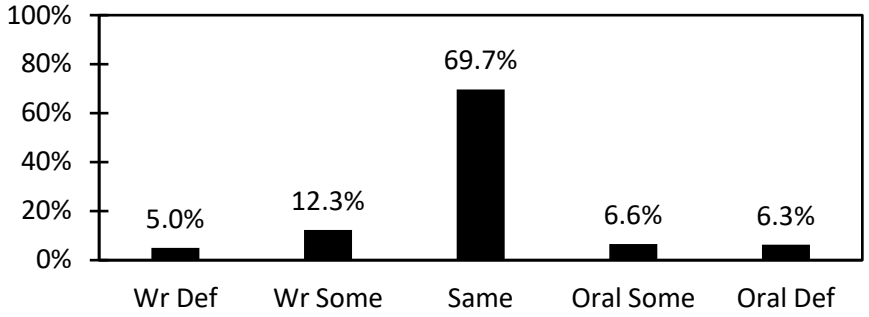

Figure 5: Survey Results for the Question "Which exam was graded fairest?"

Oral exams and neurodiverse students. Exams can be stressful for many students. It is important to consider whether one-on-one oral exams inherently misrepresent the abilities of neurodiverse students. This is a difficult question. Chrysochoou and colleagues [18] stated that oral presentations may be a better way for some dyslexic students to demonstrate their understanding of engineering principles. Wakeman and coworkers [19] suggested oral exams as an alternative for neurodiverse students in a fluid mechanics course during the COVID 19 pandemic. Clearly, there is no "one size fits all" answer.

Anecdotally, only one out of almost 400 students refused to take the oral exam in the CIE 442 course, citing extreme discomfort in the exam setting. Although offered an alternative, this one student elected not to take the exam. Numerous students expressed anxiety prior to the exam. Typically, the first minutes of the exam were devoted to creating a calm, professional environment to minimize anxiety. No data were collected on the neurodiversity status of the students.

Academic integrity issues. Each student was required to sign a pledge immediately after the exam, promising not to discuss the exam until all students had been tested. In spite of this precaution, it is of interest to test whether later-testing students had an advantage. This hypothesis was tested in two ways. First, to test whether later-testing students did better than their peers, the correlation between exam scores and the order in which the students took the exam (hereafter, exam order) was determined. The exam order was recorded for 9 out of the 15 years in this study. A typical profile is shown in Figure 6 for 2016. In all nine years, the 95% confidence interval (CI) for the slope of score versus exam order included zero.

Second, a measure was calculated to see if students performed better on the oral exam than expected. This measure was Δ(rank) = rank in the course – rank on the oral exam. (The rank in the course includes the oral exam.) The Δ(rank) values are plotted versus exam order in Figure 5 for 2016. In 2016, the 95% confidence interval for the slope of score versus order was entirely positive. The 95% CI included zero for the other years.

Although these measures are fairly crude, there is no evidence that later-testing students performed better than their peers or better than expected.

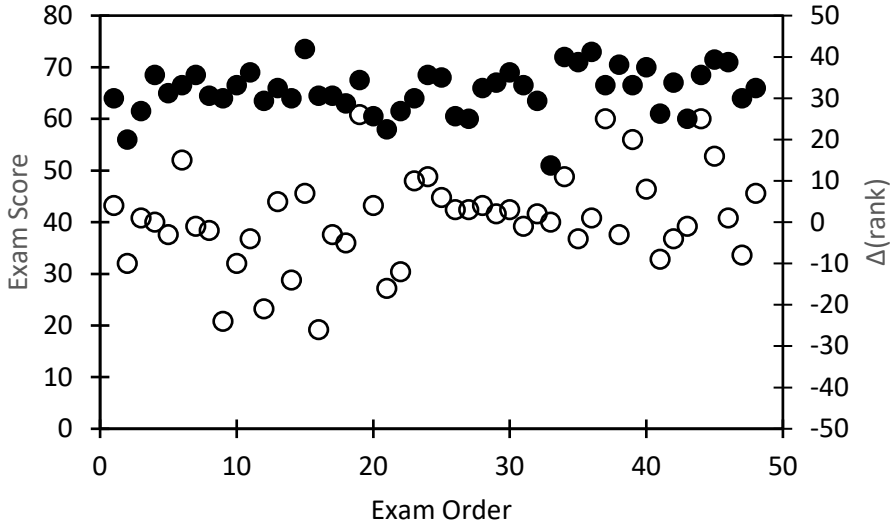

Figure 6: Data to Test Whether Later-Testing Students Performed Better (filled circles: exam score, open circles Δ(rank), 2016 data)

Practical Issues

Scalability. Due to the one-on-one nature of oral exams, they may be perceived as more time-intensive for instructors than written exams. As implemented in this course, the oral exam was graded during the exam. Therefore, the simple calculus in scalability is whether the duration of an individual oral exam is greater or less than the time required to grade one written exam. In the author's experience, execution and grading of the oral and written exams in the target course required approximately equal time commitments.

Score variability. It is interesting to note that the oral exams scores were much less variable than written exam scores. Relative standard deviation (RSD) values for the two written exams, quiz, and oral exams are given in Figure 7.

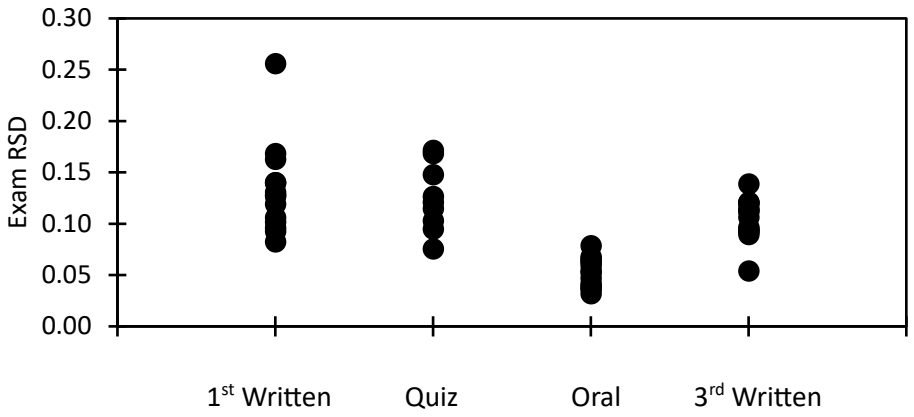

Figure 7: Variability of Exam Scores

It is likely that the lower variability is due to more partial credit awarded that was possible because of the interactive nature of the exam. Scores were lowered if the student required a prompt. In a written exam setting, no response would receive a score of zero. The lower variability in scores also may reflect the quick decision-making required during real-time grading of the exams, as opposed to more contemplative grading possible for a written exam. Differences in grading between oral exams and transcripts of oral exams also was noted by Thomas and coworkers [16].

Role of Oral Exams in Environmental Engineering Education

When asked for their exam preference in engineering courses, respondents expressed a preference for written exams, although nearly one-third of respondents indicated they preferred an equal number of oral and written exams (All Written: 4.9%, Mostly Written/Some Oral: 58.9%, Equal: 31.6%, Mostly Oral/Some Written: 4.3%, All Oral: 0.3%). These responses indicate a desire on the part of students for more oral exams in the curriculum.

It is interesting to note that although students reported that the oral exam was more helpful to them professionally, they prefer written exams overall. This might be due in part to the perceived value of oral exams in design courses. When asked which engineering courses are best suited for oral exams, respondents overwhelming reported that oral exams are more suited to design courses (Analysis courses: 1.9%, Design courses: 85.5%, All courses: 11.3%, No courses: 1.3%).

CONCLUSIONS

Data collected over 15 years was used to evaluate the role of oral examinations in environmental engineering design courses. Students perceived that oral exams were of more value to them than written exams in achieving their professional goals. Over 85% of students reported that oral examinations were more suited to design courses rather than analysis courses. Responses to an open-ended question supported the idea that students performed at integrative learning levels during the oral exam. Students indicated a slight preference to oral exams regarding the evaluation of their knowledge. It appears that student performance is about as variable between

testing modes (quiz vs oral) as it is across subject matter. Students reported that both written and oral exams were administered and graded fairly. Students tested at the end of the testing period did not appear to perform better than their peers or than expections, suggesting that academic integrity issues were not significant.

REFERENCES

[1] R.M. Felder, D.R. Woods, J.E. Stice, and A. Rugarcia, "The Future of Engineering Education II. Teaching Methods that Work," *Chemical Engineering Education*, Vol. 34, No. 1, pp. 26-39, 2000.

[2] A. L. Darling and D.P. Dannels, "Practicing Engineers Talk About the Importance of Talk: A Report on the Role of Oral Communication in the Workplace," *Communication Education*, Vol. 52, No. 1, pp. 1-16, 2003.

[3] V. Villarroel, D. Boud, S. Bloxham, D. Bruna, and C. Bruna, "Using principles of authentic assessment to redesign written examinations and tests," *Innovations in Education and Teaching International*, Vol. 57, No. 1, pp. 38-49, 2020.

[4] Engineering Professor's Council Working Party on Assessment, "Assessment Methods in Engineering Degree Courses. A Discussion Document Prepared by the EPC Working Party on Assessment," Engineering Professor's Council Occasional Paper No. 5, December, 1992.

[5] N. Delson, S. Baghdadchi, M. Ghazinejad, M., Lubarda, M. Minnes, A. Phan, A., C. Schurgers, and H. Qi, "Can Oral Exams Increase Student Performance and Motivation?" Presented at the 2022 ASEE Annual Conference & Exposition, Minneapolis, MN, 2022.

[6] Olin College Curricular Decision Making Board. Once Upon a College or The Olin College Curriculum (A Play in Five Acts), undated. https://static1.squarespace.com/static/61a9b8d68a45fd0747e2f0a1/t/622b6e6936aa8d72b0de2169/1647013482150/3528278.pdf_file.pdf. Viewed January 2024.

[7] D. Lines, "Developing a Variety of Assessment Methods, Including Self and Peer-assessment. An Overview," Presented at the Assessment Workshop Series No. 4, Developing a Variety of Assessment Methods, Scottish Higher Education Enhancement Committee, Robert Gordon University, March 19, 2004.

[8] A.A. Berezin, A.A., "A Solution to Cheating," *ASEE Prism Online*, October, 2000.

[9] N.P.W. Coe, P.A. Rowland-Morin, K.W. Burchard, J.L. Garb, and P. Friedmann, "Factors Affecting the Evaluation of the Oral Examination," *Current Surgery*, Vol. 49 (September), pp. 459-464, 1992.

[10] J.B. Biggs, and K.F. Collis, *Evaluating the Quality of Learning. The SOLO Taxonomy (Structure of the Observed Learning Outcome)*. New York, NY: Academic Press, 1982.

[11] T. Olsson, "Qualitative Assessment in Engineering Education, The Swedish Council for the Renewal of Higher Education Project No. 053/99, Final Report," April, 2005.

[12] P. Lundgren, "Effects of Elective Oral Examinations in a Semiconductor Devices Course for Computer Engineering Students," *International Journal of Engineering Education*, Vol. 14, No. 4, pp. 294-299, 1998.

[13] A. Crannell, "Collaborative oral take-home exams," In *Assessment Practices in Undergraduate Mathematics, MAA Notes Number 49*, ed. B. Gold, S. Keith, and W. Marion, Washington D.C.: The Mathematical Association of America, 1999), pp.143-145, 1999.

[14] J.P. East and J.B. Schafer, “In-person grading: An evaluative experiment,” In *Proceedings of the 36th SIGCSE technical symposium on computer science education*, pp. 378-382, 2005.
[15] J. Hackworth, “Oral Exams Are No Panacea,” *ASEE Prism Online*, December, 2000.
[16] C.S. Thomas, G. Mellsop, K. Callender, J. Crawshaw, P.M. Ellis, A. Hall, A., J. MacDonald, P. Silfverskiold, and S. Romans-Clarkson, “The Oral Examination: A Study of Academic and Non-academic Factors,” *Medical Education*, Vol. 27, pp. 433-439, 1992.
[17] L.W. Anderson, (ed.), D.R. Krathwohl (ed.), P.W. Airasian, K.A. Cruikshank, R.E. Mayer, P.R. Pintrich, J. Raths, J., and M.C. Wittrock, M.C., *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman, 2001.
[18] M. Chrysochoou, A.E. Zaghi, and C.M. Syharat, Reframing neurodiversity in engineering education. *Front. Educ.*, 7:995865, 2022.
[19] C. Wakeman, A. Bagtzoglou, and M. Chrysochoou. Improving the Learning Experience of Neurodiverse Students in a Fluid Mechanics Course During the COVID-19 Pandemic. Presented at the 2022 American Society of Engineering Education Northeast Conference, Boston MA, April 2022.

Appendix: Survey Questions and Allowed Responses

1. Please answer the following questions comparing the written and oral exams you had in this course. Which type of exam:

Best evaluated my knowledge of the course material?
Was administered fairest?
Was graded fairest?
Will help me in my professional goals?

[Allowed responses for each: Written definitely, Written somewhat, About the same, Oral somewhat, Oral definitely]

2. Please indicate your thoughts on the types of exams you would like to see in engineering courses (circle one):

All written
Mostly written with occasional oral
Even mix of written and oral
Mostly oral with occasional written
All oral

3. Which engineering courses are best suited for oral examinations (circle one)?
Analysis courses (statics, etc.)
Design courses
All courses
No courses

4. Please write any additional comments on the exams you have had so far in this course: