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Students Attitudes on STACK Content: A Pilot Study at the University of Trieste, Italy

Zevick Otieno Juma
University of Trieste, ITALY

Elisabetta Chelleri
University of Trieste, ITALY

Daniel Doz
University of Trieste, ITALY

Danilo Lewanski
University of Trieste, ITALY

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Abstract

Background: Online examinations are increasingly prevalent in educational settings, offering innovative assessment methods. Understanding student perceptions and experiences with such systems is essential for enhancing their effectiveness and acceptance in educational practice.
Aims: This pilot study aimed to examine the impact of STACK (System for Teaching and Assessment using a Computer algebra Kernel)-based online exams on various facets such as student comfort, perceived value for learning and exam preparation, preferences between pen-and-paper versus STACK formats, confidence in online math tests, readiness to adopt online assessment platforms, and overall perspectives on online evaluations.
Method: An experimental within-subjects design and convenience sampling were used to involve 117 first-year biology students enrolled in a Probability and Statistics course who were already familiar with the STACK system. Data were collected using pre- and post-exam online surveys featuring five-point Likert scale questions and an open-ended query.
Results: The findings indicate that students felt more comfortable using the STACK system after the study and preferred it over traditional exams. Nevertheless, some students expressed uncertainty about using STACK content for final exams due to concerns about its effectiveness in evaluating critical thinking and potential technical difficulties. However, concerns regarding technical challenges decreased significantly post-exam, with no technical issues reported during the exam. Positive feedback highlighted STACK's benefits for formative assessment, easier learning, immediate feedback, and its practicality and innovation. Some students even suggested incorporating STACK into final exams for convenience and advocated for further investment in the STACK system, possibly with improved content.
Conclusion: In summary, students preferred using STACK for exams, though concerns about technical glitches and the need to refine content for assessing critical thinking persist. Future efforts should focus on enhancing content quality, starting this summer.

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INTRODUCTION

Gagné's theory of learning, which encompasses nine instructional events, highlights the critical importance of assessment, positioning it as fundamental to the learning process (Gagne, 1985). This framework posits that effective assessment is crucial at various stages of learning to reinforce knowledge acquisition and ensure long-term retention. Consequently, this has led to considerable discussion on how to optimize learning through assessment (Li & Schoenfeld, 2019). Recently, there has been a significant shift towards the adoption of technology-driven assessment methods, driven by the recognition that traditional paper-based assessments may not fully exploit the potential of dynamic and interactive methods enabled by technology (Cézar et al., 2021). As a result, educators are increasingly exploring innovative assessment tools and platforms to enhance the learning experience and foster deeper engagement among students (Hsu & Wu, 2023; Tursyngozhayev et al., 2024).

*** Corresponding author:**
Zevick Otieno Juma, University of Trieste, ITALY. ✉ zevickotieno.juma@phd.units.it

Building on this shift towards technology-driven assessment methods, the COVID-19 pandemic has profoundly impacted education worldwide, sparking discussions about the necessity to restructure assessment methods. The abrupt transition to remote and hybrid learning models necessitated by the pandemic compelled educators to rethink traditional assessment approaches. As Zhao and Watterston (2021) have highlighted, the challenges brought on by the pandemic have accelerated these discussions, leading to an increased awareness of the limitations inherent in traditional assessment methods within remote learning environments. Educators and researchers have recognized the need for more adaptable, technology-enabled assessment strategies that can effectively support remote and online learning modalities. In response to these challenges, educational institutions have increasingly adopted online assessment tools to facilitate remote learning and assessment. The use of online assessment tools has grown significantly in recent years, as evidenced by studies from Csapó and Molnár (2019), García-Peñalvo et al. (2021), Juma (2023), and Zerva (2020). These studies have documented the widespread implementation of online assessment platforms across various educational contexts, from primary schools to higher education institutions. The growth of online assessment tools can be attributed to several factors, including the need for greater flexibility, time-saving assessment methods, and advancements in technology that have facilitated remote learning. Additionally, the aim to provide students with a more interactive and engaging educational experience has driven the adoption of online assessment tools, as highlighted by Serutla et al. (2024).

In line with the shift towards technology-driven assessment methods, a notable example of an online assessment tool is STACK (Systems for Teaching and Assessment using Computer Algebra Kernel), which stands out as a remarkable tool tailored for STEM subjects (Sangwin, 2015). With its open-source plugin accessible through platforms like Moodle, STACK revolutionizes teaching, learning, and assessment practices across STEM disciplines. Powered by the open-source computer algebra system, Maxima, STACK empowers educators to create dynamically generated mathematical questions within structured templates (Sangwin, 2015). This feature not only enhances the efficiency and systematization of teaching but also fosters personalized learning experiences for students. Furthermore, STACK's structured models rigorously evaluate student responses, providing targeted feedback tailored to the specific types of errors encountered (Moodle Plugins Directory, 2024). Importantly, STACK's impact extends beyond its technical functionalities to its real-world applications in diverse educational settings. For instance, researchers at Maseno University, Kenya (Juma, 2023), conducted a study on the effectiveness of STACK on learner engagement, performance, and perception in mathematics. Their findings underscored the positive correlation between STACK scores and end-of-semester exam results, highlighting its effectiveness in enhancing student learning outcomes.

Additionally, the University of Birmingham (Sangwin & Hermans, 2013) reported on the use of STACK in mathematics education, emphasizing its role in addressing criticisms of traditional assessment methods and fostering valid assessment practices. Similarly, in Finland, researchers explored the correlation between STACK performance and exam grades, revealing insights into student behavior and learning patterns. This study demonstrated the positive impact of STACK on student engagement and problem-solving skills in mathematics education (Mäkelä et al., 2016). Furthermore, the development of Portable STACK in Japan (Nakamura et al., 2013) showcased STACK's adaptability and accessibility, providing students with convenient access to mathematics exercises and promoting independent learning. These examples highlight STACK's versatility and efficacy in various educational contexts, from Africa to Europe and Asia, reinforcing its significance as a transformative tool for teaching, learning, and assessment in STEM disciplines.

As education continues to evolve with technological integration and pedagogical advancements, understanding learner experiences with these tools becomes paramount. According to Olasina (2023), piloting these tools in various contexts is essential to provide insights into their effectiveness, tailor their integration to meet diverse student needs, and contribute to the ongoing evolution of pedagogical practices. This approach aids in the development of evidence-based strategies for the use of technology in education. Furthermore, students are not passive recipients of education but active participants whose attitudes are shaped either by pedagogy or through the general perception of the subject as a whole (Acosta-Gonzaga & Walet, 2018; Han & Liou-Mark, 2023). This understanding underscores the importance of continually assessing and adapting

educational tools to enhance learning experiences and outcomes. As such, incorporating student feedback and experiences into the development and refinement of technological tools is crucial for ensuring their effectiveness and acceptance in educational practice.

Many research studies on student experiences with online examinations utilizing technological tools have revealed a spectrum of outcomes encompassing both positive and negative aspects. Tai et al. (2022), employing the Technology Acceptance Model (TAM) in a quantitative survey, identified the benefits of online assessments, particularly accentuated during the COVID-19 pandemic. Their research established significant correlations between perceived ease of use, usefulness, and various advantages linked with online assessments, including enhanced accessibility, streamlined administration processes, and the provision of prompt feedback. Moreover, the reduced anxiety reported by students can be attributed to several factors, supported by theories such as Lazarus and Folkman's Transactional Theory of Stress and Coping (Krohne, 2002). Online assessments provide a less socially intimidating environment, reducing anxiety associated with peer and authority figure presence.

Additionally, the autonomy offered by online assessments aligns with Deci and Ryan's Self-Determination Theory (Vallerand, 2000), fulfilling students' psychological needs for autonomy and competence, thereby reducing anxiety levels. These findings resonate with similar conclusions from Butler-Henderson & Crawford's (2020) systematic review, which examined student perceptions, performance, and anxiety related to online examinations. Similarly, Raman et al. (2021) reviewed the types, architecture, challenges, and prospects of online proctored examinations. Their work, focusing on the student adoption experience, provides insights into the effectiveness of online examinations. The advantages reported by students, such as preventing time loss, reducing exam anxiety, and quickly learning exam results, align closely with the benefits highlighted in this study, strengthening the foundation for understanding the multifaceted nature of student experiences with online assessments (Raman et al., 2021).

The impact of gender on online assessment in STEM education is a complex and multifaceted issue (Idrizi et al., 2023). For instance, a correlational study found that female students outperformed males in online STEM courses, a discipline that has traditionally been male-dominated, highlighting the individualistic nature of engagement in such courses and making gender-based generalizations and assessments of online tools in STEM complex (Idrizi et al., 2023). Another study highlighted the potential of the anonymity and flexibility offered by online learning environments to attract more females to STEM studies, thereby mitigating gender disparities (Wladis et al., 2015; Wood et al., 2021). Conversely, some research suggests that males might possess advantages in online classrooms, attributed to their higher perceived ability, comfort, and engagement with technology (Korlat et al., 2021). This continuous shift in findings from the literature emphasizes the importance of continued investigation and refinement for understanding in this domain. In this pilot study, sex differences were examined to identify the impact of using STACK content in exams on the two groups, aiming to shed light on the complex dynamics identified in existing literature. The pilot course under investigation comprised 85 (73.5%) females and 31 (26.5%) males. Recognizing this imbalance as a potential limitation in interpreting the analysis, this study highlights it as a focal point for further exploration in future studies. In critiquing the existing landscape of research on student experiences in online examinations, several key considerations emerge. Firstly, concerns about the reliability of online assessments have been raised, with factors such as technical glitches, internet connectivity issues, the potential for cheating, and the ability to assess critical thinking skills beyond computational abilities casting doubt on the credibility of these evaluations (Beliauskene & Yanuschik, 2021; Juma, 2023).

Despite the numerous studies on online assessments, the prevailing positive results in student perceptions are often skewed towards non-STEM fields, revealing a notable gap in understanding how students in science, technology, engineering, and mathematics respond to online assessment tools (Chen et al., 2018; Meng et al., 2014). Amid this gap, STACK emerges as a focal point for investigation due to its emphasis on STEM subjects, integration of computer algebra systems, and potential impact on pedagogy in diverse contexts such as the Italian education system. This study was specifically designed to investigate learner perceptions of the use of STACK Technology for assessment in exams, extending beyond regular formative assessments. The University of Trieste, Italy, intends to integrate the STACK system in undergraduate STEM courses. It is essential to

understand how students perceive and adapt to digital assessment tools like STACK. By tailoring educational practices to the local context and addressing any specific challenges, this research aims to contribute to the broader understanding and effective implementation of STACK in diverse educational settings.

The Context: University of Trieste

The University of Trieste (see Home Page | Università Degli Studi Di Trieste, n.d.) is a public research university in northeast Italy, consisting of 10 departments, about 15,000 students and 1,000 staff. The University was founded in 1924 and celebrates its first-century anniversary this year. Initiatives in STEM education, with special attention to digital didactic, are a pivotal aspect of UniTS's commitment to staying at the forefront of educational practices. In this outlook, the Department of Mathematics, Informatics, and Geosciences (MIGe) of UniTS plays a crucial role at UniTS. MIGe incorporates the former Departments of Informatics and of Mathematics and Geosciences, which are recognized, and the latter, which the Italian Ministry of Education recognizes as a Department of Excellence. MIGe stands out for its approach, addressed to an international and highly qualified target: in fact, its didactic offer is taught mostly in English (66% of Bachelor degree courses and 80% of Master degree courses are taught in English), and talented students are recruited from all over the world, also thanks to the support of University College "Luciano Fonda," which every year offers accommodation and scholarships to MIGe talents with fewer opportunities.

Through the years, MIGe set out relevant cooperation with national universities (e.g., a Master's Degree program in Scientific and Data-Intensive Computing is organized with the University of Udine) and international HEIs (MIGe releases two double degrees: one Master's degree in Geophysics and Geodata with the Institute de Physique du Globe from Paris and one master degree in Mathematics with the University of Ljubljana). Peculiar is the MIGe connection with the most important national (e.g., National Institute of Oceanography and Applied Geophysics – OGS, Area Science Park) and international research centers (e.g., International School for Advanced Studies – SISSA, ICTP) and industries, which give constant inputs and feedbacks on the current and forthcoming scientific, research and market needs. On the basis of this cooperation, MIGe updates and renews its didactic offer punctually (the international Master's Degree program in Data Science and Artificial Intelligence and the Master's Degree program in Scientific and Data-Intensive Computing started in 2023), normally with an interdisciplinary approach (intense cooperation is set with the Departments of Physics, Engineering, and Architecture), as an essential element to offer concrete solutions to existing issues.

In the pursuit of modernizing assessment methodologies, the Department of Mathematics, Informatics, and Geological Sciences strategically decided to start four pilot courses with the STACK system in 2023/24: (1) Probability and Statistics within the BSc of Biotechnology, (2) Linear Algebra taught in one unified course for Mathematicians and Physicists, (3) Linear Algebra in one unified course for Civil Engineers and Environmental Engineers, (4) Linear Algebra in one unified course for Naval Engineers and Mechanical Engineers. In these courses, STACK educational material was made available and employed to support students with additional exercises for self-assessment and extra feedback. In courses (1) and (3), STACK has been employed for continuous assessment, the grading counting in a relatively small percentage on the final grade (10% in course 1. and 7% in course 3.). Furthermore, in the course (1), the STACK system's ability to manage online mathematics exams was tested. The adoption of the STACK technology at UniTS aligns well with the university's strategic decisions towards the national objectives of modernizing higher education within the Piano Nazionale di Ripresa e resilienza (National Plan of Recovery and Resilience, PNR). PNRR has, is, and still will provide a considerable amount of funding to projects aligning with its objectives. For example, two PhD positions at UniTS were funded in 2023/24 within the framework of improvement of the public administration for projects specifically involving STACK, its impact and development, and also in relation to machine learning techniques. UniTS MIGe Department initiated the use of STACK in the Italian environment and might further develop its internal use. It might also provide support and feedback to other national institutions that will decide to spearmint its use within their courses. MIGe has also led several outreach activities in high schools as well as public engagement activities for the general public. The Department furthermore collaborates with the Accademia

Nazionale dei Lincei, one of the oldest Science Academies of Europe established in Rome, organizing sponsored training programs for high school science teachers at the National level.

METHOD

Experiment Overview

The experiment comprised two phases: a traditional written exam followed by an online STACK exam. This section provides an overview of the experimental procedure. Figure 1 illustrates the flowchart outlining the process.

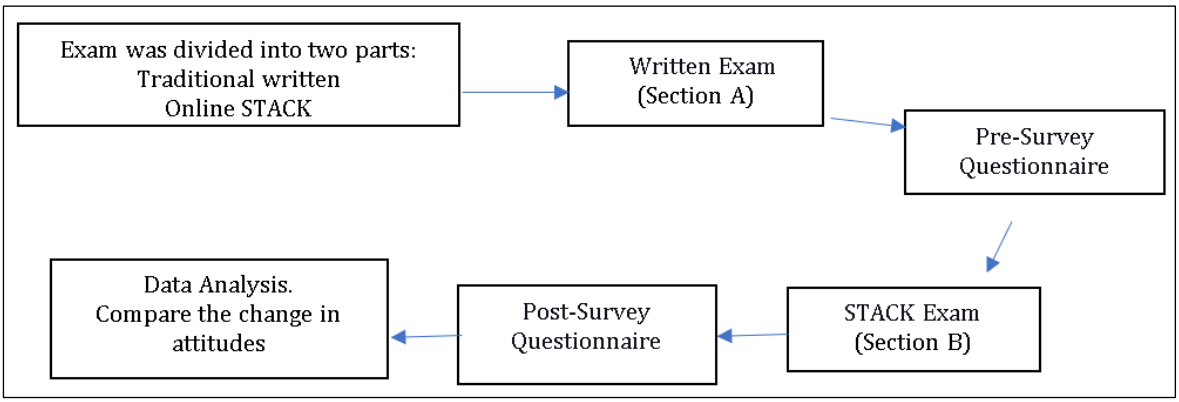

Figure 1. Experiment Overview Flowchart

The subsequent sections describe in depth the elements that made up this research methodology.

Research Design

This research was an experimental within-subjects design. In a within-subjects design, all participants experience all levels of the independent variable or conditions of the study, and the outcomes are compared between the conditions (Charness et al., 2012). The rationale for choosing this design was to assess changes in attitudes within the same group over time.

Participant Demography

This study involved 117 students from the Department of Life Science, specifically Biotechnology undergraduates at the University of Trieste (UniTS), in particular, 85 (73.5%) females and 31 (26.5%) males (Figure 2).

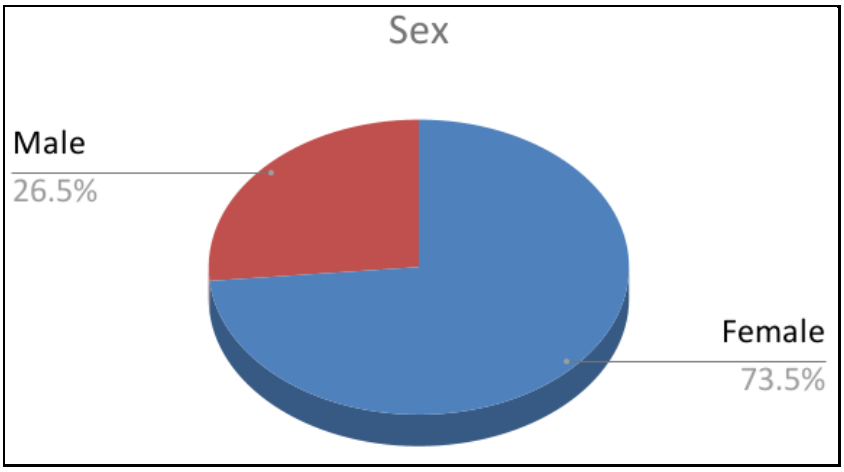

Figure 2. Participants' Demography

The students involved in this study had prior exposure to STACK content during their practice assessment exercises in a course that spanned 40 hours over 6 weeks. Out of the 117, 115 (98.3%) students responded to the online questionnaire, which had ten items rated on a five-point Likert scale and 2 open-text comments. Two students did not provide any response.

Participant Response Rate

The students involved in this study had prior exposure to STACK content during their practice assessment exercises in a course that spanned 40 hours over 6 weeks. Out of the 117, 115 (98.3%) students responded to the online questionnaire, which had ten items rated on a five-point Likert scale and 2 open-text comments. Two students did not provide any response.

Exam Structure

The course of general mathematics was subdivided into two sections: starting with 32 hours of calculus (derivation, integration, sequences, and analysis of functions' behavior), the course then delved into 40 hours (distributed within 6 weeks) of Statistics and Probability. The examination process began with a pen-and-paper exam covering the calculus section. The students then handed in the analysis exam for regular human-led assessment and accessed UniTS Moodle via either a laptop or a tablet. Personal smartphones were not allowed, except to generate a hotspot in the rare cases when the personal device does not connect easily to the *Eduroam* wifi network of the University.

The students then access the STACK Exam via Moodle by inserting a password that was shared on the board by the lecturer the very morning of the exam. The exam was also only accessible during the morning of the exam, was timed to stay open for 100 minutes after opening, and was set up to accept automatically pending open attempts that were not handed in before 100 minutes. This measure was adopted to make sure that if the button to hand in the exam is frozen (which indeed happened in rare cases), the exam was not lost. It could also happen that the student was so focused on the exam that he forgot to hand it in on time: with this measure, all the solved problems were still submitted for evaluation.

Data Collection

At the commencement and conclusion of the exam, students were requested to participate in a brief survey comprising five multiple-choice questions, evaluated on a 5-point Likert scale for students to express their opinions on various aspects of the examination experience, such as comfort, confidence, and receptiveness to technological adaptation. The Likert scale allowed for the quantification of responses given, enabling us to analyze and compare the responses efficiently (Bertram, 2007). Additionally, a final open-ended question solicited comments (refer to Appendix I). These questions gauged levels of comfort, confidence, receptiveness to technological adaptation, and overall attitudes toward online examinations.

Data Analysis

Data analysis was done using SPSS version 20 for quantitative analysis and Google Spreadsheet for qualitative data. Descriptive statistics, such as the mean (M) and standard deviation (SD), offered insights into the average participant response and the variability in opinions. Inferential statistics, such as paired t-tests, were calculated with the degrees of freedom (df) also computed to assess the statistical significance of changes before and after using the STACK system.

The qualitative responses from students were analyzed using an inductive coding approach (Chandra & Shang, 2019). This involved breaking down the responses into smaller samples, developing codes to cover each sample, and then applying these codes to the data. The process was iterative, with new codes being developed based on the data and existing codes being reviewed and potentially revised. This approach was done to capture students' sentiments both before and after they took the online exam in STACK, i.e., in the pre-post survey. In presenting the qualitative analysis, the average of pre-post responses was computed to rank the themes in order of magnitude. To guarantee the accuracy of the coding system, all the authors independently reviewed students' answers, and the discrepancies that emerged were discussed through research meetings.

RESULTS AND DISCUSSION

Results

In this section, we present the study's findings, focusing on the evolution of students' attitudes and perceptions regarding online examinations following their engagement with the STACK system. Table 1 illustrates the paired sample statistics for the questionnaire items analyzed in the study.

Table 1. Paired Samples Statistics

		M	*SD*	*t*	*df*	Sig. (2-tailed) 95 % Confidence
Pair 1	Comfort with Online Exams (Pre-STACK Exam) *(1)Very Uncomfortable … (5) Very Comfortable*	3.10	.892	-.696	114	.488
	Comfort with Online Exams (Post-STACK Exam) *(1)Very Uncomfortable … (5) Very Comfortable*	3.16	.951			
Pair 2	Preference for Exam Format (Paper vs. STACK) *(1) Strongly Prefer Paper… (5) Strongly Prefer Online*	2.42	.908	-3.289	114	.001
	Shift in Preference for Exam Format (Paper vs. STACK) *(1)Shifted Toward Paper..(5) Strongly Shifted Toward Online*	2.71	1.058			
Pair 3	Confidence in Online Mathematics Exam (Pre-STACK Exam) *(1) Not Confident at All … (5) Extremely Confident*	3.06	.798	-1.985	114	.050
	Confidence in Online Mathematics Exam (Post-STACK Exam) *(1) Decreased Significantly...(5) Increased Significantly*	3.25	.804			
Pair 4	Willingness to Adapt to STACK Exams (Pre-STACK Exam) *(1) Not Willing at All …(5) Very Willing*	3.67	.824	2.573	114	.011
	Willingness to Adapt to STACK Exams (Post-STACK Exam) *(1) Not Willing at All …(5) Very Willing*	3.45	.881			
Pair 5	Overall Attitude Toward Online Exams (Pre-STACK Exam) *(1) Very Negative … (5) Very Positive*	3.27	.732	-.568	112	.571
	Overall Attitude Toward Online Exams (Post-STACK Exam) *(1) Very Negative … (5) Very Positive*	3.31	.791			

Students' comfort with Online Exams showed a marginal increase post-STACK (M_{post} = 3.16) compared to pre-STACK (M_{pre} = 3.10), with the *t*-statistics indicating no significant difference (p = .488) at 95% confidence level. The shift in preference from traditional paper-and-pencil exams to online methods was statistically significant, with a *p*-value of .001 and a significant increase in mean statistics (M_{pre} = 2.42 to M_{post} = 2.71). Students generally had a positive confidence towards online exams with STACK. The confidence in Online Mathematics Exams saw a slight rise post-STACK (M_{pre} = 3.06 to M_{post} = 3.25). However, the result is borderline (p = .050, which is equal to a 95% confidence level), and the study concluded this was a significant improvement based on the increase in the average responses.

Willingness to adapt to new technologies remained positive post-STACK, although there was a slight decrease in mean willingness scores from M_{pre} = 3.67 to M_{post} = 3.45, which was also statistically significant (p = .011). The overall attitude toward online exams was generally positive, with a mean attitude score of M_{pre} = 3.27, pre-STACK, showing a slight improvement to M_{post} = 3.31 post-STACK, but statistically insignificant (p = .571).

Figure 3 presents a comparative analysis of the thematic responses before and after the STACK exam, with a visual representation of the number of students' responses that revolved around that theme before and after using STACK in the exam. The major themes derived from the analysis encompass concerns regarding STACK's ability to assess critical thinking skills, recognition of the advantages of the online exam format, and the prevalence of technical challenges leading to anxiety. Additional insights from the identified is a spectrum of student sentiments ranging from fear and stress associated with online exams to a lack of fear or stress, varied perceptions of the effectiveness in assessing reasoning abilities, preferences for traditional exams, timely feedback delivery, and the convenience of the assessment method, confidence and efficiency with online exams, positive perceptions of online exams as a novel and beneficial innovation for learning and practice, willingness to adapt to innovation, recommendations for question improvement, concerns related to access issues such as devices, internet, and space, and positive experiences with a clear exam

structure. These diverse themes provide a comprehensive overview of student experiences and opinions related to online exams with the STACK platform.

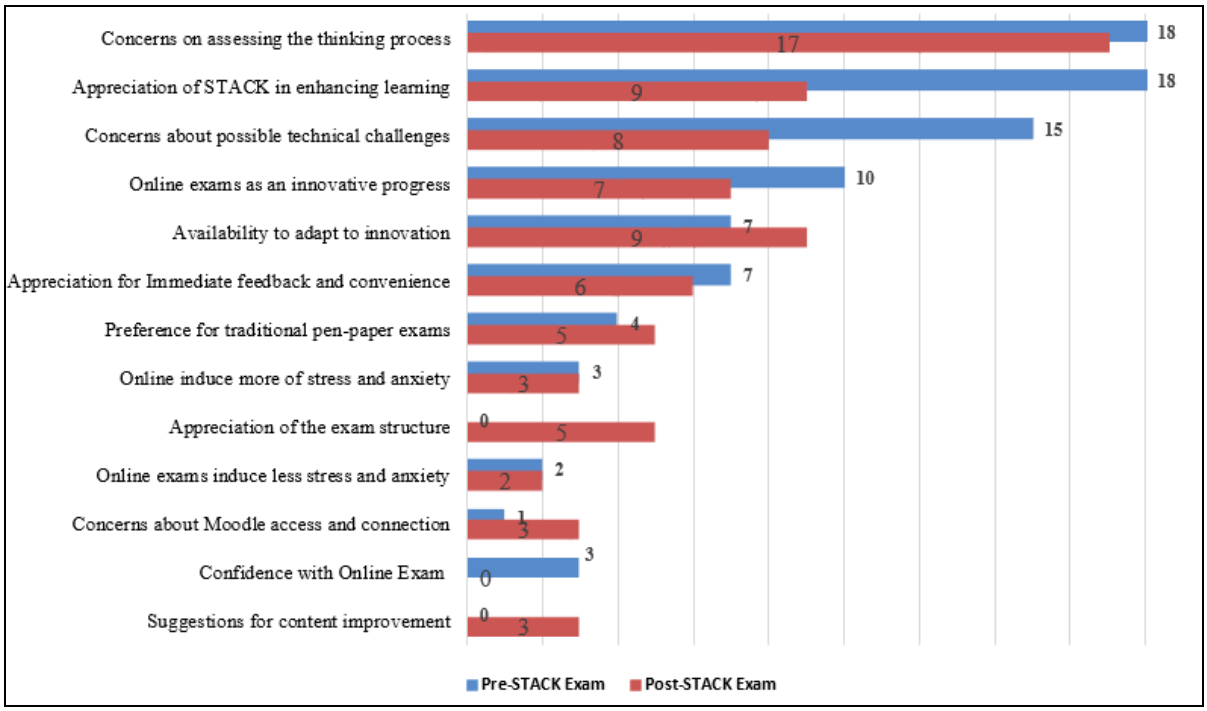

Figure 3. Comparative Analysis of the Identified Themes from the Responses Before and After the STACK Exam

On average (before and after the STACK exam), one salient concern highlighted by students revolved around doubts regarding how effectively the STACK content used assessed thinking process, with twice the number of females (18.82% of the 85 females in the study) than males (9.68% of th 31 males in the study) raising this point. The numbers equalized Post-exam, with a total of 16.47% females and 16.13% males mentioning it. This was despite females performing better than males in the exam. This apprehension had diverse opinions, with some expressing the need for the materials to be reviewed by the lecturer before confirming their grades. In contrast, others outrightly oppose its integration for assessment for the same reason that its content mainly focuses on the final answer and not the thinking process. For instance, some students wrote texts showing concerns about the inconvenience of online exams compared to traditional pen-and-paper assessments, citing challenges in the evaluation process and the rigid format enforced by STACK.

Student 099
Original Text - *[...se si potesse inserire una parte del procedimento si riuscirebbe a valutare anche quello e non solo il risultato inserito]*
Translation - [...if you could somehow take into account the student's steps to the result, you would be able to evaluate that too and not just the final result]

Student 042
Original Text - *[Ritengo che Gli esami online siano comunque una valida alternativa a quelli cartacei. E se si ripresentasse l'occasione di svolgere un esame con queste modalità, non avrei nulla in contrario. Ma continuo a preferire quelli cartacei, che seppur meno "comodi" lasciano maggiore libertà di pensiero per quanto riguarda procedimento e svolgimento.]*
Translation - [I believe that online exams are a valid alternative to paper exams anyway. And if the opportunity arises again to take an exam in this manner, I would have nothing against it. But I still prefer the paper-based ones, which, although less 'convenient,' leave more freedom of thought as far as the solving process is concerned].

Student 005

Original Text - *[Rimango dell'opinione che gli esami online siano molto più scomodi rispetto al cartaceo. Credo che con carta e penna sia più facile valutare il procedimento, mentre su Stack conta solo il risultato finale (ad esempio, potrei avere eseguito il procedimento corretto ma aver fatto un banale errore di calcolo in questo caso Stack dà tutto sbagliato, mentre magari nel cartaceo sarebbe stato valutato positivamente almeno il procedimento). Inoltre, l'esame online mi obbliga a usare una forma rigida per scrivere i risultati, anche se a volte questa forma non è sicuramente la più comoda (nel primo esercizio avrei potuto scrivere la probabilità del punto d come rapporto fra coefficienti binomiali, invece ho dovuto per forza scriverla come frazione ridotta ai minimi termini, cosa che a mio parere è un po' inutile).]*
Translation - [I remain of the opinion that online examinations are much more inconvenient than on paper. I believe that with pen and paper, it is easier to evaluate the solution process, whereas, on Stack, only the final result is accounted for (e.g., I might have carried out the correct procedure but have made a trivial calculation error in which case Stack gives everything wrong, whereas perhaps in paper at least the procedure would have been evaluated positively). In addition, the online exam forces me to use a rigid form to write down the results, even though sometimes this form is certainly not the most convenient (in the first exercise, I could have written the probability of point d as the ratio of binomial coefficients. Instead, I had to write it as a fraction reduced to the smallest terms, which, in my opinion, is a bit pointless)].

The second salient theme from the student comments was grouped under the educational benefits of using the STACK content (both males and females in equal proportions encouraging it), particularly emphasizing its utility for learning through practice with feedback, especially assessment, willingness to adapt to its integration, and convenience compared to paper assessment (evidenced by the response given by student042), having clarity and easy to follow structure, among others (all of which were analyzed further and presented in the bar chart as well). While some students mentioned having anxiety with online exams, other students disagreed with this sentiment, stating that they found online exams more relaxing than paper as long as it's the same online platform used for assessment. Others even went ahead and gave recommendations, as pointed out by student099 previously. The others mentioned the following.

Student 043
Original Text - *[Sono una buona modalità per effettuare gli esami da terminale, anche grazie al fatto che si ha la possibilità di familiarizzare con STACK prima dell'esame]*
Translation - [They are a good way to carry out final examinations, partly due to the fact that you have the opportunity to get accustomed to STACK before the examination].

Student 002
Original Text - *[comodo e si ha velocemente il risultato…mi sono trovata molto bene, soprattutto per quanto riguarda lo studio. l'esame era chiaro e non necessitava di dimostrare i vari passaggi]*
Translation - [...convenient and you get the result quickly... I found it very good, especially in terms of studying. The exam was clear and did not need to demonstrate the various steps]

Student 060
Original Text - *[Penso che STACK sia utile per fare esercizio, ma viste le difficoltà riscontrate con il correttore automatico del sito (soprattutto a livello di arrotondamento dei decimali, che spesso venivano arrotondati per difetto invece che per eccesso) temo che l'esito dell'esame possa essere influenzato da questo genere di errori del sito.]*
Translation - [I think STACK is useful for practice, but given the difficulties encountered with the site's automatic corrector (especially in rounding off decimals, which were often rounded down instead of up), I fear that the outcome of the exam may be affected by these kinds of errors on the site].

Student 011
Original Text - *[Fare esame su STACK non crea ansia e pressione. Essendomi esercitata molto sulla piattaforma mi sembra normale fare esercizi tramite schermo]*

Translation - [Examining STACK does not create anxiety and pressure. Having practiced a lot on the platform, it seems normal to me to do exercises via the screen].

The third prominent theme centered around technical challenges or fear of encountering technicalities if STACK is to be used as an online assessment tool and how this induces anxiety, with more males (16.13%) compared to females (11.76%) reporting concerns about technical challenges Pre-STACK than Post-STACK (7.06% females and 6.45% males). The majority of the male students responded to this theme, having experienced and feared experiencing technical issues. This overarching theme further contributed, in part, to comments related to access to devices, the Internet, and space for taking exams.

Student 103
Original Text - [*le soluzioni agli esercizi non erano sempre comprensibili e alcune volte erano errate, questo ha aumentato la difficoltà nello studio individuale*.]
Translation- [the solutions to the exercises were not always understandable and were sometimes wrong, which increased the difficulty in individual study].

Student 038
Original Text - *[il fatto di essere costretti a procurarsi un dispositivo autonomamente vincola chi deve sostenere l'esame, la possibilità di avere un'aula già fornita di computer sarebbe meglio. inoltre i problemi riscontrati con la piattaforma STACK prima dell'esame, per quanto sistemati, lasciano un senso di inquietudine nello svolgimento dell'esame]*
Translation - [the fact of having to bring over a device independently constrains those who have to take the examination; the possibility of having a classroom already equipped with a computer would be better. Moreover, the problems encountered with the STACK platform before the examination, however, fixed, leave a sense of unease in the conduct of the examination]

Further analysis revealed that participant responses highlighting technical challenges and anxiety decreased in prevalence after interacting with the STACK Exam. However, this theme retained significance across both pre- and post-STACK responses. Analyzing the qualitative responses proved to be a complex task, especially when comparing the quantitative analysis before and after the STACK exam, with the researchers primarily concentrating on the major themes outlined earlier. While the minor themes held less prominence, their inclusion alongside the major ones was deemed valuable for capturing the diverse range of feedback.

Discussion and Interpretation of Findings

The objective of this pilot study was to examine the attitudes of undergraduate students at the University of Trieste (UniTS) regarding the use of STACK content for assessment in the final exams. The first students' concern addresses the capability of the STACK content employed to capture the full thinking process of the students at the exam, with more females (18.82%) compared to males (9.68%) expressing concerns about the material's ability to assess the thinking process Pre-STACK exam. The numbers equalized post-exam (16.47% females and 16.13% male). This was despite females outperforming males in the exam. We remark that this feedback is specific to the STACK content employed and not to STACK as a system. It is definitely possible to write STACK questions that faithfully take into account the thinking processes all the way through the exercise. A few employed questions already do that by segmenting the task into smaller steps, each of which is assessed iteratively (so making a mistake in one step does not provoke a negative evaluation in all subsequent ones). This was studied, for instance, particularly for proof-type questions, according to the works of Bickerton and Sangwin (2022). It simply takes a large number of resources (especially in terms of funding) to develop these advanced questions, taking the full thinking process into account (Nakamura et al., 2012). This is an investment that we plan to make in the near future, ideally in the form of contracting professional developers to write STACK content full-time for the University. Another way institutions go about this is to exchange high-quality questions through open-question banks, according to Nakamura et al. (2014), which has worked well to some extent. However, there is no organ in charge of certification of questions quality. It is recognized in the community that STACK courses need a few iterations to be at their best (the STACK developer Chris Sangwin stated that a good course takes three years), encouraging institutions that just started

incorporating this technology within their education system. This pilot study was necessary precisely to understand these underlying areas of improvement. We conclude the comments around this feedback on the thinking process explicitly raised the point motivated by a worry of being penalized in the evaluation, as they would normally get points distributed for sketching the thinking process, even if a final answer is not reached.

The second prominent theme was students' appreciation of STACK content for enhancing learning. More males (25.81%) compared to females (11.76%) appreciated STACK's potential in the enhancement of learning, citing various benefits of Pre-exam, such as its capacity to elevate the learning experiences, facilitate effective practice, deliver immediate feedback, simulate exam scenarios for thorough preparation, enhance student focus, and enable remote and interactive practice in formative assessments. Notably, these benefits are particularly advantageous for individuals residing at a distance or working part-time, thereby enhancing overall access to education. This has been studied especially in relation to students who thrive in a self-paced learning environment (Bishop et al., 2022; King, 2023; Sangwin 2015). This probably suggests why the results on students' comfort with online exams through STACK showed an increase, although insignificant, while on the other hand, there was a significant shift in preference towards online assessment with STACK, see Table 1. This shift in preference aligns with the broader educational landscape's trend towards innovative assessment approaches, especially in the wake of challenges posed by the COVID-19 pandemic. The significant advantages associated with online assessments, as reported in the literature (Butler-Henderson & Crawford, 2020; Raman et al., 2021; Tai et al., 2022), such as enhanced accessibility, convenience, and the ability to provide prompt feedback, likely contributed to the students' growing comfort and preference for online assessment tools like STACK. As education transitions into an era characterized by technological integration, this shift in preferences underscores the importance of adapting pedagogical practices to meet the evolving needs of students. The positive trend suggests a potential receptivity to digital assessment tools, paving the way for further exploration of innovative technologies in educational settings.

While the statistical analysis revealed a slight rise in confidence, the result is borderline with a *p*-value of .050, indicating significance at the 95% confidence level. Despite this borderline significance, the study concluded it as a notable improvement based on the observed increase in average responses. This increase in confidence can be attributed to the structured nature of STACK assessments, as pointed out by some students, and its ability to encourage others to practice with feedback in formative assessment as well as reduce exam anxiety in the process.

Some indicators may not have changed post-STACK due to factors such as prior experience or familiarity with online assessment tools (Hachey et al., 2022). Students who were already comfortable with similar platforms might not have seen significant shifts in their attitudes or preferences. Additionally, the perceived relevance of certain assessment methods could play a role (Jamil, 2012). For example, if students already felt confident in their ability to perform well using traditional assessment formats, they might not have perceived a need for change or improvement. Furthermore, individual differences in learning styles and preferences could contribute to variations in post-STACK indicators (Serutla et al., 2024). Students with diverse backgrounds and experiences may respond differently to the introduction of new assessment methods, leading to a range of responses in the post-STACK data.

The third feedback expressed concerns about possible technical issues that may arise during the online exam, with more males (16.13%) compared to females (11.76%) reporting concerns about technical challenges Pre-exam than post-exam (7.06% females and 6.45% males). In fact, almost no issues have arisen during the online exam sessions so far, and noticeably, the number of concerned students has dropped considerably from pre- to post-exam. The decline in concerns about technical issues from pre-exam to post-exam may be attributed to increased familiarity with the platform, aided by support resources and training sessions, alongside potential technical improvements made during the exam period according to works of Mahlangu and Makwasha (2023), and (Almaiah et al., 2022). The technical problems that occurred involved a single student running out of battery (which was then charged in the classroom), a single student not being able to access Moodle (which was then solved by trying a number of times), and a single student that borrowed a device from a colleague.

The insights identified from this pilot study hold implications for pedagogy in STEM education, particularly in the context of the University of Trieste (UniTS), the Italian education system, and other

institutions considering the integration of tech-driven assessment tools. The observed trends in student perceptions, encompassing increased comfort with online exams, a notable shift in preference toward online assessment, and a positive willingness to adapt to technologies like STACK, suggest a receptivity to digital tools among STEM students.

Connecting these insights to the broader implications for STEM education, addressing student concerns, and leveraging the advantages offered by technology can inform and shape pedagogical practices (Baleni, 2015). The increase in confidence, even if marginally significant, highlights the potential of structured online assessments, such as those facilitated by STACK, in fostering a more positive learning environment (Beliauskene & Yanuschik, 2021; Erskine & Mestel, 2018; Juma, 2023; Oyengo et al., 2021). The immediate feedback mechanism not only enhances the learning process but also aligns with the principles of formative assessment according to Gagne's (1985) theory of learning, enabling students to practice with feedback and, in turn, reducing exam anxiety. However, the study also unveils certain challenges, particularly regarding the perceived lack of rigor in testing critical thinking skills. This discrepancy emphasizes the need for ongoing refinement and improvement in technology-driven assessments. Acknowledging the advantages and challenges identified in the study, educators can tailor their pedagogical approaches to address these nuances, ensuring a balanced integration of technology into STEM education (Facer, 2011; Singh, 2021).

The study's variations in perceptions, diverse attitudes toward online assessment, and distinctions in learning benefits contribute to a richer understanding of the complex nature of student attitudes toward STACK. Moreover, the empirical evidence presented in this study contributes to the ongoing discourse on the advantages and challenges of STACK Assessment in STEM disciplines. This contextualized contribution is particularly relevant to the Italian academic landscape, where institutions like UniTS are new to the implementation of STACK. The findings offer valuable insights that can guide institutions undergoing a similar transition to online assessment with the STACK system, contributing to the enhancement of STEM education practices in Italy and beyond.

Limitations

The following issues were identified as potential limitations in the study.

1. Non-Response Bias: The study recognizes the possibility of non-response bias in qualitative data analysis. Acknowledging that these cases may not have captured the sentiments of the entire student body, this bias could result from the content or satisfied individuals being less inclined to provide feedback or vice versa, potentially skewing qualitative findings towards more critical viewpoints.
2. Selection Bias of First Trial Students with Online Exams in STACK: Involvement of first trial students in the study raises awareness of potential selection bias as well. While their experiences are valuable, it's acknowledged that their responses might not be fully representative of the broader student population. First-trial students are generally the best ones and could possess other distinct characteristics or motivations that influence their perceptions, limiting the generalizability of findings to students with more experience. These initial characteristics of first-trial students were not captured before the research started.
3. Fatigue and Post-Exam Disposition: The study recognizes the influence of factors like fatigue and post-exam disposition on students' responses. Acknowledging the possibility that students eager to leave after the exam might provide hurried or less thoughtful feedback, it's understood that these factors could impact the depth and accuracy of qualitative insights.
4. Novelty Effect: The study underscores the potential of the novelty effect associated with the first online exam experience and, for some, the first university exam ever. While this novelty adds richness to the data, it's acknowledged that it could introduce biased perceptions, as students may lack a basis for comparison.
5. As mentioned in the literature review, the interplay between sex and technology acceptance is intricate and subject to ongoing debate. Recognizing the sex imbalance within the pilot course (73.5% females, 26.5% males) as a limitation, more piloting will be done in other courses with various student enrolments.

Suggestions

Moving ahead, the following areas were identified as points for further investigation:

1. Conducting a longitudinal study to track students' perceptions and attitudes towards online examinations with the STACK system over an extended period, allowing for a deeper understanding of how these attitudes evolve with continued exposure and experience.
2. Comparing the attitudes and performance of students using the STACK system for online examinations with those using traditional pen-and-paper assessments, exploring potential differences in outcomes, preferences, and experiences. Supplementing quantitative findings with qualitative data to gain a richer understanding of students' experiences, attitudes, and concerns regarding online examinations with the STACK platform.
3. Investigating the effectiveness of interventions aimed at addressing specific concerns raised by students, such as enhancing the ability of STACK questions to assess critical thinking skills or providing additional support for technical issues, and assessing their impact on student attitudes, performance, and satisfaction to inform strategies for optimizing the use of the STACK system in educational settings.

CONCLUSION

In evaluating student responses to the STACK system, several benefits and areas for improvement have been identified. The flexibility in the evaluation tree structure offers both challenges and opportunities, such as the use of a tolerance node to reduce stress in exercises involving descriptive statistics. Student feedback highlights the need for STACK to better consider the thinking process, which can be addressed by segmenting exercises into multiple steps to track reasoning. The study found sex-based differences in responses, with more females concerned about the system's ability to assess thinking processes, though these concerns equalized after the exam. Despite females outperforming males, more males appreciated STACK's benefits, such as immediate feedback and convenience. Logistical challenges, like device availability, have been mitigated by allowing tablets, though further solutions, such as computer lab rotations, are needed. Minimal technical problems were reported, and a session to familiarize students with STACK syntax is proposed to alleviate stress. The randomization of exercise parameters also helps deter cheating, making STACK a valuable tool for enhancing STEM education.

AUTHOR CONTRIBUTION STATEMENT

ZOJ: Conceptualization, Methodology, and Supervision. ZOJ led the initial conceptualization of the study and developed the research methodology. ZOJ also provided overall supervision throughout the research process, ensuring the study's alignment with academic standards and objectives.
EC: Data Collection and Analysis. EC was responsible for collecting the data and conducting the statistical analysis. EC played a crucial role in interpreting the data and providing insights into the findings, contributing significantly to the results section of the paper.
DD: Writing – Original Draft Preparation and Visualization. DD handled the initial drafting of the manuscript and was responsible for creating visual elements such as charts, graphs, and diagrams. DD also ensured that the manuscript adhered to the journal's formatting and submission guidelines.
DL: Review and Editing, Funding Acquisition. DL contributed to the critical revision of the manuscript, providing detailed feedback and suggestions for improvement. DL also secured funding for the research project and managed resources necessary for the study's completion.

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