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Developing a Framework for Personalized Video-Based Quantum Information Science Education

Nikos Chrisochoides
Old Dominion University

Norou Diawara
Old Dominion University

Michail Giannakos
Norwegian University of Science and Technology

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Developing a Framework for Personalized Video-Based Quantum Information Science Education

Nikos Chrisochoides
Computer Science Department
Old Dominion University
Norfolk, USA
nikos@cs.odu.edu

Norou Diawara
Math & Statistics Department
Old Dominion University
Norfolk, USA
ndiawara@odu.edu

Michail Giannakos
Department of Computer Science
Norwegian University of Science and Technology
Trondheim, Norway
michailg@ntnu.no

***Abstract*—This is a white paper on Workforce Development for Quantum Information Sciences (QIS) led by the Center for Real-Time Computing at Old Dominion University (ODU). We plan to investigate the potential of video lectures in supporting QIS. Specifically, we focus on following four objectives: (a) design a two-course series for both Master-level and PhD students; b) an upgrade of Experimental Lecture System (ELeSy) to test new, innovative, and transformative approaches for inclusive QIS education; c) design and implementation of a mixed-method systematic empirical study on the effects of video learning styles (in-person flipped classroom and voluntary video use) on graduate students' QIS studies, and d) integration of the empirical results and requirements and development of a framework with practical (e.g., best practices) and technical (e.g., systems' design guidelines) knowledge, addressing how instructors and developers can increase video lecture benefits by incorporating AI-based learning tools. The contributions of our white paper are a) methodology for evaluating a novel experimental video analytics system, b) the systematic empirical evaluation of video lectures as a learning technology for QIS, and c) motivating the discussion on how instructors and developers can increase video lecture benefits. The project results (over the next three to five years) will be shared with the broader community and participants.**

***Index Terms*—video lectures, quantum information science (QIS), workforce development, higher education, online learning, flipped classroom, AI in education.**

I. Introduction

In this project, we will focus on the graduate-level QIS curriculum and research-based assessment, which are also under development by other groups, such as the University of Colorado [45], which will consult us on this project. With the widespread adoption of online video lecture communities, such as Khan Academy, and specifically for QIS state-of-the-art content developed by top companies like IBM, it has become critical to research how students learn via video lectures. A significant body of related research into the impact of video lectures has been made ([41]; [63]; [4]). However, most previous efforts have been mainly focused on (1) a sporadic or one-time use of video lectures in an educational context ([11]; [29]) or (2) the investigation of only a single factor like student performance ([32]; [38]) and to the best of our knowledge none studies QIS topics. Video lectures have given rise to flipped (or inverted) classrooms [19]. This type of blended learning classroom utilizes technology, such as video, to move lectures outside the classroom, giving students and teachers time for active learning in the classroom [53]. Assay validity measurements need to be clearly defined to assess these new tools. Engagement is pivotal in the validity and efficacy of learning and course development. While technical and infrastructural developments [53] make the potential of video-mediated learning ripe for exploration, previous academic research on the use of video lectures has not addressed: (1) casual students and, in our case, upskilling in QIS in (2) measuring the overall learning behavior for (3) prolonged periods. We contend that the most compelling effects of video QIS lectures on students' learning behavior have not yet been documented. There is a much-needed effort for more effective and efficient program preparedness in QIS delivery. In this proposed research, we aim to explore the benefits and perspectives of video QIS lectures to support graduate student project-driven learning. We seek to answer the following two questions:

- What opportunities and challenges do video lectures provide for graduate students in QIS education?
- How can video lectures extend and enhance student learning, specifically the critical thinking and problem-solving skills essential to make them quantum-aware and quantum-ready?

To address the above research questions, we will focus on the following three objectives:

- Update an existing open-source Experimental Lecture System (ELeSy) used in [4].
- Scenarios design and implementation of a mixed method systematic longitudinal empirical study on the effects of QIS video learning styles (flipped classroom and voluntary video use) on students' learning practices [16].
- Integrating the empirical results and requirements and developing a framework with practical (e.g., best practices) and technical (e.g., systems' design guidelines) knowledge, addressing how QIS instructors and developers can

increase video QIS lecture benefits [16].

With the efforts described in this white paper, we aim to discover strategies for QIS project-driven learning. We will break down the lecture notes and videos by importance and relevance to the project. The videos first present the most critical why," is discussed. In summary, the focus of our research activities will be: (1) conduct a systematic longitudinal empirical examination to test the effect of video lectures and flipped classroom teaching on students' overall learning in QIS and (2) analyze the empirical data that are necessary to provide a framework for efficient video learning. ELeSy can have a broader impact on the community through the results of empirical research and with the learning analytics tool for video lectures (ELeSy), which will be available for further improvement and experimentation. Given the resources we request and the target student population, we have chosen three Computer Science graduate students' classes in QIS: (1) "Introduction to Quantum Computing", an in-person class for freshman graduate students, and (2) "Utility-Scale Quantum Computing", an online advanced graduate student classes. The lectures we will create are specific to the study course levels; however, the methodology and lessons learned with a different set of video lectures can apply to other QIS classes, STEM topics, and disciplines nationwide. The data gathered will assess levels of engagement and success to ensure productive learning outcomes.

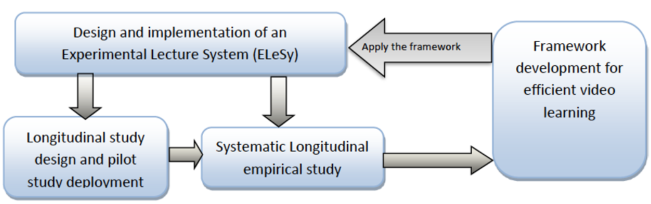

Fig. 1. Graphical representation of the overall research approach.

II. Related Work

Video lectures have emerged as one of the premier media for learning. Many instructors in higher education are implementing video lectures in a variety of ways, such as broadcasting lectures in distance education [49], delivering recordings of in-class lectures with face-to-face meetings for review purposes [2]; , and delivering lecture recordings before class to conserve class time and flipping the day for hands-on activities ([7] [20]). Other uses include showing videos demonstrating course topics ([24]; [57]) and providing supplementary video learning materials for self-study [8]. Researchers have delineated video lectures' educational advantages and disadvantages (e.g., [44]; [63]; [54]). However, previous efforts have been mainly focused on the sporadic use of video lectures and investigating a specific feature. Our study will formally evaluate the effects of video lectures in several specific learning environments, including the traditional classroom, the flipped classroom, and voluntary student access, on students learning over a long period of time with different and various types of measures.

With the increased availability of technological applications over the past 20 years, educators have been able to draw on these tools to enhance classroom learning. Furthermore, the flipped classroom approach provides a way for classroom time to focus on learning content at a deeper level ([13]; [62]). The use of video in flipped classrooms is one of the key components to providing the lecture out-of-class time [53]. Key assumptions from the cognitive theory of multimedia learning [42] may explain the efficacy of video lectures to enhance student learning. Research in Dual Coding Theory suggests that a learner's cognitive system (memory) includes two separate pictorial and verbal processing channels. Presenting information that accommodates both channels allows a learner to better understand the material by integrating information from both channels [42]. Empirical studies [22] confirmed these assumptions by showing that students learn and communicate better from words and pictures than from words alone. Other studies on video lectures covering the public sector government documents (Library Hi Tech), marketing [29], and higher education ([1]) argue that if video lectures are developed properly and account for individual learners as much as possible, they may contribute to intrinsically motivating, meaningful learning. To that end, our main goals are (1) to examine the relationship between traditional and contemporary teaching methods and technologies through a carefully designed experiment and the rigorous interpretation of our results and (2) to identify best practices and design effective instructional frameworks to improve student spatial intelligence and performance on spatial ability tasks [66], specifically emphasizing QIS courses of study.

Learning is a multidimensional process/experience, which includes emotional, social, and cognitive components. In face-to-face instruction, teachers use their voices and movements and address learners with impromptu questions and stories. A teacher's personality often creates an atmosphere conducive to learning [48]. Learner emotions can greatly contribute to the learning environment. Emotions negatively or positively affect students' intrinsic motivation, which, in turn, leads them to concentrate cognitive resources and, in some cases, pursue learning beyond what is delivered in the classroom. On the other hand, video lectures are accessed on a computer screen and are limited by the teacher's perspective of the content filtered through technological processes. In video lectures, teacher-student interactions cannot be identical to those experienced through traditional teaching in the classroom. We will correlate the results with other measures (e.g., performance) and the video lecture content from diverse lecture "styles" like those developed for IBM's Summer Programs on Quantum Computing [67] relying on a more mathematically grounded approach) to a more approachable video lecture "style" for beginners developed by M. Nielsen 15 years ago [47]. Potentially, styles of video lectures might vary; we noticed that students demonstrate different preferences based on their perception of the "style" of the video lectures. The "style" could be another variable in this study, as long as we can define concise characteristics instead of the crude description given above.

Video lectures allow teachers to disseminate content across large distances, increasing access for students in universities with limited instructional resources. Advocates of this delivery media suggest that well-designed video lectures can improve cognitive understanding and information processing by increasing student motivation and engagement ([60]; [59]) , resulting in conceptual learning gains [27]. Yet, from current research, it is difficult to tell what specific aspects of the video lectures provide positive impacts. To employ video lectures that serve as powerful pedagogical tools, care should be taken to examine the impact of video lectures on the visual and motivating capabilities of the curricula (e.g., QIS). In summary, the proposed research aims to explore if and how video lectures impact students' learning and determine if it makes a difference when and how students access video lectures.

Regarding the performance of students using video lectures, researchers have reported that the use of video lectures has resulted in significant gains in measurable skills [61], standardized test scores [63], and course grades ([64]; [68]). The research suggests that video lectures can improve student learning. Consistent with the assumptions from the cognitive theory of multimedia learning [42] and considering that multimedia facilitates meaningful contexts [6], researchers predict that video lectures can enhance student performance by presenting well-designed instructional messages that support cognitive development. Reviewing students' perceptions of video lectures, students described video lectures as enjoyable to watch [24], satisfying [63], motivating ([31]; [58]), intellectually stimulating [12], useful, helpful, and effective with respect to improving learning ([32]; [41]). Students who have used video lectures have generally reported that the use of these technologies had a positive effect on their exam performance or their learning, in general, while helping them to study more efficiently [2], and that they intend to use them again in the future (of course, what they believe is not always consistent with what happens). Current research, specifically analysis of student perceptions, reveals several issues concerning student understanding of video lectures. In this work, we will formalize a general framework regarding students' perceptions and the impact of these perceptions on their intentions to use video lectures for learning and upskilling purposes. Regarding students' actual use of video lectures, students enjoy control over when and where they learn [31], what they need to learn [30], and the pace of their learning ([3]; [25]). In addition, for those students using video lectures, improvements in study habits have been observed, including a fostering of independence [34], an increase in self-reflection [40], the heightening of efficient test preparation [43], and the practice of reviewing of material more regularly [50]. Learner control in well-designed video lectures can be beneficial in terms of convenience and supplemental practice [26]. Students report a variety of reasons for using video lectures. [65] indicated that students widely use video lectures for revision and review during exam preparation. When video lectures are available, students typically use them. For instance, [28] found that almost all students (95–97%) viewed video lectures at least once. These findings suggest that students are using video lectures when offered for various subjective and objective benefits and that students perceive video technology as a practical learning resource. However, some aspects remain unexplored: are students viewing the entire video lecture; what segments of the video lecture do students select to view, and why; how many times do students view any given video lecture; do they prefer real-world QIS use cases or simpler QIS kernels that may be available on video and not in the traditional classroom; and what video applications are more attractive or engaging, individually or in groups. To address these critical issues, this study will try to shed light on students' multi-faceted interactions with video lectures. Our motivation for this project is based on emerging developments. First, using videos for learning has become widely employed ([4]; [16]; [21]). Video-based technological tools have been developed, and many educational institutions and digital libraries have incorporated video into their instructional materials. Second, despite the growing number and variety of video lectures available, there needs to be more understanding of their effectiveness in how students learn QIS from video lectures. Specifically, more research is needed regarding guidelines for using video QIS lectures and the design of hands-on pedagogical systems. For example, it is established that learners benefit from highly structured learning material, but the manual editing of video is only feasible for some learning organizations and instructors.

III. Experimental Lecture System

The Experimental Lecture System (ELeSy) uses the Internet and cloud-based technologies. The ELeSy web video player will be based on (1) YouTube Application Programming Interface (API), (2) Google App Engine, and (3) Eclipse (Java). The development tools can be seamlessly integrated into a flexible architecture (Figure 2); based on this architecture, we have already developed a functional prototype of ELeSy ([4]; [16]). In addition, we can use HTML to create the buttons we want for our experiment (in addition to the standard buttons: Play, Stop, Pause, see Figure 1, right) and JavaScript to implement their functions. Navigational affordances will be added to collect data that examine student behaviors while viewing videos. For instance, we will develop a Rewind and Forward button. The first one goes backward 30 sec, and its main purpose is to replay the last viewed seconds of the video, while the second jumps forward 30 sec, and its main purpose is to skip "undesired" video segments. More importantly, we can record and collect data from all students' interactions with the video, which is impossible for researchers today. Most of these data are collected by existing vendors like YouTube but are not available to the research community.

The YouTube API exposes some important events, such as Stop or Pause. Moreover, it provides methods for controlling the timing of the video. Alternative video APIs could also be used if they allow developers to control the current state of the video. During the project's three-year life, we will constantly reevaluate pertinent state-of-the-art technologies to improve the ease of use and portability of the ELeSy platform.

We will create accounts for all students using ELeSy to sign in and watch the video lectures. Thus, users' interactions will be recorded and stored alongside their account data (coded and anonymized to protect the identity of the students). When a student visits the ELeSy website, she will see the following elements on the screen (Figure 3): 1) the web video window, 2) the video buttons, 3) a submit button, and 4) sometimes a pop-up survey/test. Pushing one of the player buttons has two effects. First, the video player acts according to the function indicated by the button pressed. Simultaneously, we will add the specific interaction in a local buffer. The interactions are stored in the Data Store when the student pushes the submit button. Figure 3 depicts an example where the proposed functionality is demonstrated with the CHSH inequality, which extends Bell's inequalities and is named after the authors Clauser, Horne, Shimony, and Holt. The CHSH protocol is at the heart of the 2022 Nobel Prize for Physics awarded to Alain Aspect, John Clauser, and Anton Zeilinger in part for their pioneering work in quantum information science.

Finally, an additional tool will be used in the development process of ELeSy. Questionnaires will be employed next to the main ELeSy player, and the respective data will be integrated into the Data Store. Figures 2 and 3 present the proposed system's architecture and interface. Several results will be drawn concerning students' interactions and questionnaire responses. We will be able to locate the video lectures' content that the students skip/re-watch, and then, through content analysis, we will categorize this content and try to understand why students skipped or re-watched it.

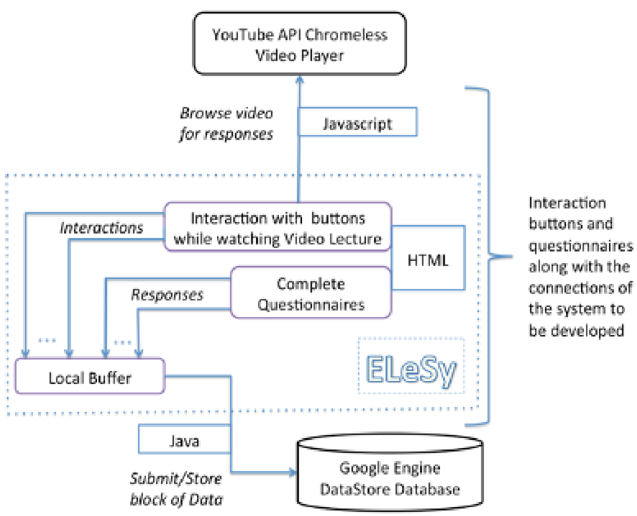

Fig. 2. The proposed architecture of ELeSy and the Interface.

IV. Research Design

The research design consists of four steps and employs four data collection methods with three groups of students; we will follow the four main steps (see Figure 4). Two experiments

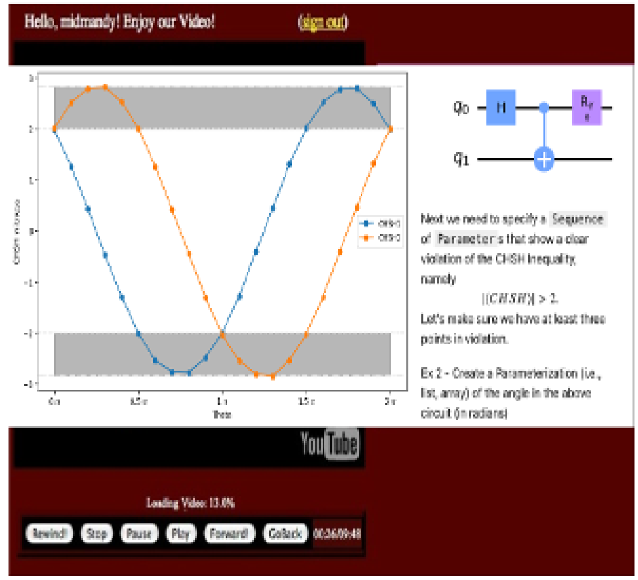

Fig. 3. The proposed Interface of ELeSy displays the results from CHSH inequality.

will be conducted, one on a traditionally difficult topic and one on a traditionally easy topic of QIS. The classification of "easy" and "difficult" topics is based on our experience teaching QIS and that of other experts in the workforce development community. The first step is the formation of the three groups. The student body to sample from (approximately N students in first-year graduate students through advanced PhD students interested in becoming quantum-aware) will be established with a pre-test mainly for required backgrounds like linear algebra, complex numbers, and Python. Based on the pre-test scores, students will be clustered into three groups. The thresholds for the scores and groups will be based on assessment proficiency levels as follows: students whose scores are below level will be part of Group A, students whose scores are on the level will be in Group B, and students above level will be in Group C. Since the number of students to sample from each group might differ, we will use a design analysis based on unbalanced repeated measurements ([35]; [36]). In doing so, we will randomly select students from each group, decreasing the bias in the results and the over-representation of just one group. In the second step, each group will enroll with the respective treatment: 1) the first group will not use video lectures, 2) the second group will use the video lectures for homework before the class (a flipped classroom), and 3) the third group will use the video lectures in their own time as supplementary material. The students will use Jupyter Notebooks (with Auto-grader built-in) during and after each lecture. In addition, we will use a capstone project at the end of the semester. Students will choose a project or creative activity of interest from a list of projects where QIS has the potential to demonstrate quantum utility in the Noisy Intermediate-Scale quantum era (NISQ-era). In the third step, we will employ the following data collection methods (measures) for each of the three groups of students:

- Interactions with the video lectures, recorded using the log files from ELeSy,
- Performance, measured by content tests,
- Perceptions, using pop-up surveys based on factors affecting students' decisions,
- Emotions regarding the video lectures, using semi-structured interviews.

All four measures will be employed throughout the experiment to record the students' learning behavior with the video lectures in three different phases: the beginning, middle, and final phases. In the fourth step, an appropriate analysis for each set of data will be employed to address the differences among the three respective groups in the two selected QIS topics (traditionally "easy" and "difficult"). Figure 4 depicts a design flowchart of the longitudinal empirical study.

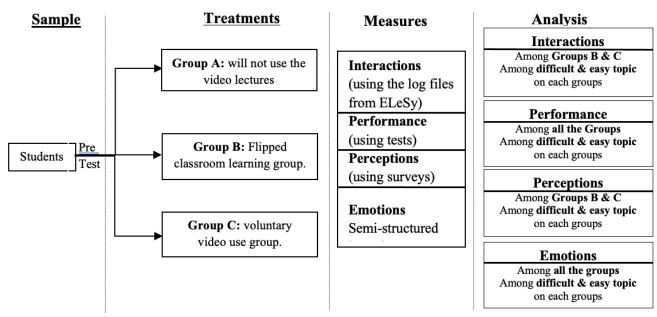

Fig. 4. Graphical representation of the research design of the experiments for each of the traditional easy and difficult QIS topics we will select based on IBM's Lecture notes and Homework from IBM's Summer Program on Quantum Computing (John Watrous, 2024).

A. Content

As stated above, we will conduct two experiments, one on a traditionally easy topic and one on a traditionally difficult topic. To engage students in QIS education, we will leverage PI's experience (and his advanced Ph.D. students focusing on QIS) for technology-based learning [46]. We will use IBM's online QIS courses (or modules) as the content (https://learning.quantum.ibm.com) of our study and both IBM and NVIDIA simulators installed at the High-Performance Computing (HPC) cluster at ODU. To do so, we selected topics the students typically find easy and difficult based on an analysis of prior classes the PI has already taught using the same material. Based on these results, we will use Teleportation and Superdense Coding protocols as the easy topic (75% performed at a proficient level) and QFT Algorithm as the complex topic (25% performed at a proficient level). These two topics provide the appropriate content in terms of a regular semester-long course, and the students are exposed to notation, proofs, and complex and constructive notions (i.e., algorithmic thinking, problem-solving), which are helpful for students' reasoning skills ([56]; [39]).

B. Sampling

Old Dominion University's student population is approximately 24,000 undergraduate and graduate students; of these, 33% are from minority groups that are underrepresented in STEM disciplines, and 55% are females, and its online program (ODUGlobal) is split into 60% female and 40% male. Gaining this multiculturalism perspective is very important [5], as we will be able to identify potential differences in the learning patterns among the different demographic group categories (race, gender, economic status, and disability) in a diverse metropolitan institution of higher education in southeastern Virginia [10]. In any given term (semester), we anticipate having between 8 to 10 students from the College of Sciences (Computer Science, Math, Physics, and Chemistry/Biochemistry) and Engineering (Electrical and Computer Engineering).

The first step in the experimental study is to select the three groups (the traditional learning-control group, the flipped classroom-experimental group, and the supplementary (voluntary)-experimental group) that will participate in the experiment. Given the above demographics, the groups will be balanced based on performance (for required material/classes) and a pre-test. The pre-test will be similar (in size and question type) to the regular homework assignments from past years. In time, the pre-test will vary to include questions that require more analytical skills and critical thinking. For each of our experiments (with easy and difficult topics), we will have three groups with high similarity in their performance and educational background. To have a power of 95% or more with a level of significance set at 0.05, the sample from each group will be set at n students (n to be determined, depending on the numbers of students registered and our ability to get statistically sound data). Detailed explanation is presented under the the subsection E of the research design section. Figure 5 depicts the formation of the groups where each of our experiments is exhibited. The "easy topic" group will be for fresh graduates (or advanced undergraduates), and the difficult topic group will be for advanced PhD students, assigned to the chosen three Computer Science classes in QIS.

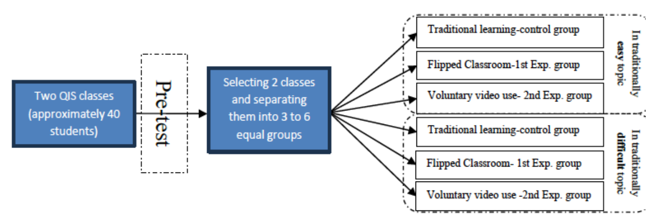

Fig. 5. The formation of the three groups in each one of our experiments.

C. Measures

To address the research questions we target in this project, subsequent projects, and different STEM courses, we will collect a wide range of data, including log files from the ELeSy, performance test results, survey results, and interviews.

Interactions: One of the primary data collection methods will be the student learning interactions; in other words, the interactions of the students with the system (i.e., Play, Pause, Stop, etc.) using the extra buttons that we will develop. With the assistance of those interactions between the students and the system (log files), we can address questions like what content students watch several times and what content students skip. Interactions will also allow us to identify potential differences among groups B and C students and the difficult and easy content. Also, these data types allow us or others to add pop-up quizzes or scaffolds in the future, which will automatically start in the right part of the dashboard (see Figure 3).

Performance: Performance data will be collected to investigate the relationship between video lectures (non-use, flipped classroom use, and voluntary use) and students' performance. Performance tests will be used at various times in the experiment. The PI (teacher) will develop these tests with the same length and question type as the regular past tests. These tests will be performed during regular classroom periods to test the performance of all the groups (and non-video lectures). Each group's performance will be evaluated using qualitative and quantitative data we collect through ELeSy to analyze how the process of understanding was affected by each educational procedure (group) and by the degree of difficulty of the chosen QIS topics.

Perceptions: In addition to testing the performance of all students, those using the video lectures will report their perceptions of the system at various times during their interactions. The tool we will use to collect students' perceptions will be pop-up attitudinal questions that will survey students' understanding of the material and perceptions of the system at the beginning, the middle, and the end of the experimental study. In particular, the proposed system (ELeSy) can use pop-up surveys on the screen and store the results in our system database. The surveys will be divided into three parts. The first part will include questions for some information regarding the students (age, gender, educational level, and topic). The second part will include measures of the various constructs identified in the literature from previous research. For instance, in one of the prior studies, we have identified constructs like 1) Self-Efficacy, 2) Perceived Behavioral Control, and 3) Social Norm, which are important for the video lectures ([23]; [18]; [33]). In all cases in this part of the study, we will use a 7-point Likert-type scale. The third part will include questions that will be free to enter from the students. These questions will be generic (i.e., How do you feel when you are using video lectures?) as they will be coded with MAXQDA (www.maxqda.com/) and NVivo (/www.nvivo10.com/) to make the appropriate qualitative analysis using several widely accepted coding protocols (e.g., [52] constructionist computer-based learning activities).

Emotions: A qualitative approach will be adopted to study the students' emotional situation when they enroll in the video lectures. Semi-structured interviews will be undertaken on a non-probability voluntary sample of the students. Non-probability sampling is common in qualitative research. An interview schedule of three stages, beginning (beg), middle (mid), and end (final), will be used to promote a more focused approach [51]. Interviews will be tape-recorded and analyzed through content analysis in the data analysis phase of the project. For more information on semi-structured interviews, we have example questions and some basic rules extracted from our prior experience [16] with semi-structured interviews.

D. Data Analysis

As mentioned above, the research will be based on a wide range of data, including log files, performance test results, survey responses, interviews, and observations. Both qualitative and quantitative methods will be used to analyze the data. For the case of quantitative data (interactions, performance test results, survey responses), we will use SAS® and IBM SPSS statistical software for the analysis. For the qualitative data (survey responses, interviews, observations), we will use MaxQDA and NVivo. As such, a proper analysis method will be used for each data type.

For the case of students' interactions, we will use the data from log files produced by ELeSy. In the first step, we will analyze the log data between Group B and Group C (using Fisher's exact test) to identify differences (if any) among the video lecture usage of these two groups. In the second step, we will interpret the system's log data with the video lectures' content using student activity graphs. This interpretation will allow us to shed light on several interesting aspects of student-lecture interactions (i.e., which content students skip/re-watch). For the case of students' performance, test scores will be compared using the Analysis of Variance or ANOVA test (or the nonparametric Mann-Whitney U-test in the case of a non-normal distribution, with not necessarily equal sample sizes- McKnight and Najab, 2010) among 1) the three groups, 2) the easy and difficult QC topics, and 3) with the classification from the pre-tests. In the case of students' perceptions, survey results will be analyzed using quantitative and qualitative methods. In part with the various constructs (i.e., self-efficacy) where a 7-point Likert scale will be employed, we will measure students' perceptions to identify which are the most mainstream. Afterward, we will employ an exploratory correlation analysis (i.e., Pearson) among the factors to investigate possible correlations. Finally, to identify the most important factors that cause a student to adopt video lectures, we will employ a Structural Equation Modeling (SEM) with an ultimate (dependent) variable, the actual use of the video lectures from students [9].

For the case of students' emotions, the basic emotion categories will be used since they have been identified as the main emotions related to computer use [37]; The content analysis procedures will consist of the following three stages: (1) studying the emotions protocol and viewing several examples, (2) studying the interviews several times, and (3) documenting the emotional situation (using MaxQDA) of the context of the interviews. The same procedure will be made based on Price and Rogers's [52] (2004) six key aspects of constructionist computer-based learning activities (Awareness, Experience, Anticipation, Exploration, Authenticity, and Collaboration). The data collected from the studies will be coded independently by two members of our team (PI and Co-PI) who have experience in using learning environments and conducting qualitative analysis. The PI will supervise both qualitative and quantitative analyses. To ensure the reliability of the coding of the two researchers, Cohen Kappa inter-rater reliability and propensity scores will be used. Afterward, to examine the differences among 1) beg the mid and final phases, 2) the three groups, and 3) the easy and difficult QIS topics, a Fisher's exact test will be used. In addition, the results of this study will allow us to understand which emotions dominate in the enrolment with the video lectures and to identify the benefits and the weaknesses of video lectures through these six key aspects of [52].

For the case of students' mathematical discussions, Scally's (1990) [55] clinical interviews will be used. Clinical interviews were chosen for this study, as this data collection method will allow the researcher flexibility in pursuing comments made by the student. Clinical interviews can also be used to elicit and record students' discussions and thinking. The credibility of Scally's clinical interview has been determined with 83% reliability and the content validity of the instrument established. Furthermore, Scally's (1990) study provided evidence for her to claim that the instruments and scoring procedures could be used effectively by other researchers and in other settings. Following instruction, five students from each research group will be randomly interviewed. The interviews will then be scored following Scally's (1990) grading scale.

E. Statistical Model/ Data Analysis

To formulate the problem, the generalized linear equation (GLM) model is proposed and is written as follows:

$Y_{ijk} = \mu + \tau_i + \beta_j + \tau\beta_{ij} + e_{ijk},$

where Y_{ijk} denotes the score for the student in the i^{th} level of study, the j^{th} type of learning (traditional in class, flipped online or hybrid, and supplementary experimental groups $j = 1, 2, 3$), the k is the k_{ij}^{th} repeated sample observation from the i^{th} level of study in the j^{th} learning type, μ represents the overall mean score; τ_i represents the effect score of the ^{ith} level of study; β_j represents the effect in the j^{th} type of learning; $\tau\beta_{ij}$ represents the effect of the interaction between the i^{th} level and the j^{th} type of learning and e_{ijk} is the random error, with $k = k_{ij} = 0, 1, .., n_{ij}$. The total sample size $N = \sum_i \sum_j n_{ij}$ is expected to be about 30 or more, that is each level of study will have about 10 students. If that threshold is not met, we will aggregate data from multiple semesters to create a robust analysis.

As in the statistical literature, the effects are subject to the restriction that $\sum \tau_i = \sum \beta_j = \sum \tau\beta_{ij} = 0$. To have the normality of the errors met, i.e. to have the errors as independent and normally distributed $N(0, \sigma^2)$, the log or a transformation of the responses may considered. We will also consider the case where that assumption of independence is lost because the data is collected from the same student. The model is then adjusted to a repeated type of measurement model (time series), with the nesting part added; the nesting is induced from the fact that each student stays in his/her selected learning style. The data will provide a comparative measure of the 3 STEM literacy groups based on covariates such as gender and STEM degree. ANOVA tests and piecewise analysis of covariance (ANCOVA) within and between each group of students will be performed at the pre- and during exams/quizzes measures using cross-sectional time data. The overall trend can be deduced, and factors related to changes (increase or decrease) in self-efficacy, self-attention, understanding, and emotional control will be given. To reduce bias in our results, the students will be asked to be independent during the lectures, and the propensity score will be computed. The propensity score approach relies on the fact that answers from one student could be influenced by another student and some unobserved heterogeneity. Another strategy is to request responses simultaneously within each group level. We will study correlations and significant differences in the effects of videos on cognition, social, and psychological factors, as well as dependent variables.

The data will be standardized and provide a comparative measure of QC literacy adjusting for gender and other variables (age, race,...) under repeated measure linear model, accounting for clustering. With the use of cross-sectional phase steps data and the students nested within their study levels, beginners (1st-year graduate) and difficult (advanced Ph.D. students), the overall trend can be deduced, and factors related to changes (increase or decrease) in higher self-study and understanding will be given [8]. The students will be asked to be independent to reduce bias in our results, and the propensity score will be computed. The propensity score approach relies on the fact that another student and some unobserved heterogeneity could influence answers from one student. Another strategy is to request responses simultaneously. Within each group level, we will study correlations and significant differences in the effects of videos on cognition and social and psychological factors on dependent variables. We will compare the rate of change in the impacts of cognitive video based on the three years using the means in an independent two-sample t-test for paired groups and in the ANOVA form for comparing the means among the three groups. A GLM with a stepwise selection of the most significant variables will be considered. We hypothesize that videos have more significant positive psychological and physiological impacts. Students' specific profiles and cross-sectional data will be assessed. Disparities initiated by the time variations from pre, during, and post-responses will be analyzed. Moreover, even with relatively small sample sizes (of, say, 10 students per class type), our goal to maximize the predictive capabilities of our models will be achieved since we intend to take repeated scores. This will allow us to build a model that explains behaviors after using video techniques with the minimum error controlling for significant covariates.

By the end of the data analysis, we will be able to specify the opportunities and challenges of video lectures. Most importantly, we will provide technical (e.g., for the system's design) and practical (e.g., best practices) knowledge to fully exploit video lectures' benefits. Last, this knowledge will be incorporated into a framework for efficient and innovative development, and videos will be used to support learning.

V. Preliminary Results

A significant amount of research output has been produced during the last year. In previous studies, we found several factors affecting students' intentions to use video lectures ([23]; [16]), yet we found that in tasks where a greater degree of comprehension is required, video lectures and traditional learning seem to have the same performance ([15]; [14]; [18]). In addition, we found that video lectures had very low performance in complex tasks requiring additional comprehension and a great degree of consolidation, and few of the students coped with solving complex tasks after a video lecture [23]. However, we found that students (children) generally preferred videos because they felt that it is more fun, easier to use, and more helpful ([17]; [14]). Learners' interactions with the video lectures are not readily available because online video platforms do not share them. To capture and store these interactions, we have already developed a prototype of the open-source video learning analytics system [4]. This ELeSy prototype facilitates the analysis of video learning behavior by capturing learners' interactions with the video player (e.g., seek/scrub, play, pause). The system also visualizes these interactions using times series to extract all the rich information and helps us understand learner activity. In addition to the first version of the video learning analytics system, we have conducted some small-scale experiments and extracted some early insights [4].

VI. Conclusions

This white paper outlines an approach to enhance QIS education through learning analytics. To achieve this goal, we propose the following key action items:

- Develop an advanced video analytics system: Create a sophisticated platform capable of extracting meaningful data from video lectures to inform instructional improvements.
- Conduct rigorous empirical studies: Design and execute controlled experiments to evaluate the effectiveness of different video-based learning approaches.
- Identify integration strategies: Determine the most effective methods for incorporating video content into QIS curricula, considering factors such as learning styles, student demographics, and subject matter complexity.
- Create practical tools and guidelines: Develop user-friendly resources to support educators and developers in maximizing the benefits of video lectures.

By executing these action items, we aim to significantly improve student learning outcomes, provide valuable insights to the educational community, and contribute to the development of a highly skilled QIS workforce. This research will bridge the gap between theoretical knowledge and practical application, ultimately fostering a more accessible and engaging QIS learning environment. This white paper serves as a road map for achieving these objectives and invites collaboration from the QIS community to bring this vision to fruition.

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