Towards Personalized Quantum Information Learning for Dynamic Class Environment and Student Engagement

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***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 the evaluation of 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*—component, formatting, style, styling, insert**

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 (Meyer et al., 2024), 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 (Lonn and Teasley, 2009; Traphagan et al., 2010; Chorianopoulos, Giannakos, and Chrisochoides, 2014). However, most previous efforts have been mainly focused on (1) a sporadic or one-time use of video lectures in an educational context (Evans, 2008; Haygood, 2007) or (2) the investigation of only a single factor like student performance (Holbrook and Dupont, 2010; Kazlauskas and Robinson, 2012) and to the best of our knowledge none studies QIS topics. Video lectures have given rise to flipped (or inverted) classrooms (Giannakos and Chrisochoides, 2014). 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 (Roehl et al., 2013). 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 (Roehl et al., 2013) 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 be used to extend and enhance student learning, including specifically the critical thinking and problem-solving skills essential to make them quantum-aware and quantum-ready in a short period of time?

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 (Chorianopoulos, Giannakos, and Chrisochoides, 2014)
- Scenarios design and implementation of a mixed method

This white paper is fudned by the Richard T. Cheng Endowement at Old Dominion University.

systematic longitudinal empirical study on the effects of QIS video learning styles (flipped classroom and voluntary video use) on students' learning practices (Giannakos and Chrisochoides, 2015).
- 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 (Giannakos, Chorianopoulos and Chrisochoides, 2015).

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) CS545, an in-person class for freshman graduate students, and (2) CS745 (Master-level) and CS845 (PhD-level), 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.

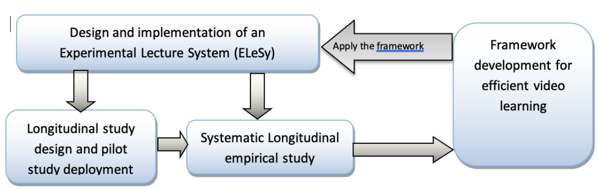

Fig. 1. Graphical representation of the overall research approach.

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 (Maag 2006; Oliver 2005), delivering recordings of in-class lectures with face-to-face meetings for review purposes (Acharya 2003; Brotherton and Abowd 2004; Harley et al. 2003), and delivering lecture recordings before class to conserve class time and flipping the day for hands-on activities (Day and Foley 2006). Other uses include showing videos demonstrating course topics (Green et al. 2003a; Shephard 2003) and providing supplementary video learning materials for self-study (Dhonau and McAlpine 2002). Researchers have delineated video lectures' educational advantages and disadvantages (e.g., McKinney et al., 2009; Traphagan et al., 2010; Brotherton and Abowd, 2004; Sanchez-Franco, 2010). 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 (Baker, 2000; Gannod et al., 2008; Strayer, 2009). The use of video in flipped classrooms is one of the key components to providing the lecture out-of-class time (Roehl et al., 2013). Key assumptions from the cognitive theory of multimedia learning (Mayer, 2001) may explain the efficacy of video lectures to enhance student learning. A fundamental assumption in the theory is derived from Paivio's (1971) Dual Coding Theory (DCT). Research in DCT 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 (Mayer et al., 2024). Recent empirical studies (Giannakos et al., 2013a) confirmed these assumptions by showing that students learn and communicate better from words and pictures than from words alone. Other studies on video lectures covered the public sector government documents (Library Hi Tech), marketing (Haygood, 2007), and higher education (Boster et al., 2007; Boster et al., 2006) 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 (Gittler and Gluck, 1998; Venkatesh et al. 2003), with a specific emphasis on 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 (Mechling, 2000; Nordkvelle et al., 2009). 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. The proposed study will investigate student emotions under learning video conditions (see Section C3). We will correlate the results with other measures (e.g., performance) and the video lecture content from diverse lectures spanning the spectrum of formal styles like those developed from IBM to less formal from Nielsen .

Video lectures allow teachers to disseminate content across large distances, increasing access for students in universities with limited instructional resources. However, research is needed to explain and measure the impact and effect of video lectures on high school students with respect to thought control, self-esteem, self-efficacy, moral values, ethics, and physiological changes. The advances of virtual high schools and online learning call for the increased use of video, but only when pedagogically appropriate and designed purposely to facilitate learning. Advocates of this delivery media suggest that well-designed video lectures can improve cognitive understanding and information processing by increasing student motivation and engagement (Oliver, 2005; Siemens, 2011; Siemens and Phil, 2011; Zhang et al. 2006), resulting in conceptual learning gains (Hargis & Wilson, 2005). 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.

A. *Learning Analytics*

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 (Alpay & Gulati, 2010; So et al., 2009), standardized test scores (Crippen & Earl, 2004; Traphagan et al., 2010) and course grades (Vajoczki et al., 2010; Wieling & Hofman, 2010). The research suggests that video lectures can improve student learning. Consistent with the assumptions from the cognitive theory of multimedia learning (Mayer, 2009) and considering that multimedia facilitates meaningful contexts (Clegg et al., 2010), 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 (Green et al., 2003b), satisfying (Traphagan et al., 2010), motivating (Alpay & Gulati, 2010; Hill & Nelson, 2011; Shih, 2008), intellectually stimulating (Fernandez et al., 2009), useful, helpful, and effective with respect to improving learning (Holbrook & Dupont, 2010; Lonn & Teasley, 2009). Students who have used video lectures have generally reported that the use of these technologies had a positive effect on their exam performance (Brittain et al. 2006) or on their learning in general (Acharya 2003), while helping them to study more efficiently (Brotherton and Abowd 2004), 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, though students often have little to no knowledge of them (Walls et al., 2010). 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 (Hill & Nelson, 2011), what they need to learn (Heilesen, 2010), and the pace of their learning (Chester et al., 2011; Griffin et al., 2009). In addition, for those students using video lectures, improvements in study habits have been observed, including a fostering of independence (Jarvis & Dickie, 2009), an increase in self-reflection (Leijen et al., 2009), the heightening of efficient test preparation (McCombs & Liu, 2007), and the practice of reviewing of material more regularly (O'Bryan & Hegelheimer, 2007). Learner control in well-designed video lectures can be beneficial in terms of convenience and supplemental practice (Hannafin, 1984). Students report a variety of reasons for using video lectures. Van Zanten et al., (2012) indicate that students widely use video lectures for revision and review during exam preparation. When video lectures are available, students typically use them. For instance, Harley et al. (2003) 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 (Chorianopoulos, Giannakos, and Chrisochoides, N. 2014; Giannakos, Chorianopoulos and Chrisochoides, 2015; Giannakos, and Chrisochoides, 2014). 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) is using 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, left); based on this architecture, we have already developed a functional prototype of ELeSy (Chorianopoulos and Giannakos, 2013; Giannakos, Chorianopoulos, Chrisochoides 2015). 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 three-year life of the project, we will constantly re-evaluate 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 2, right): 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.

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. In Figure 2, the architecture and the interface of the proposed system are presented. 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.

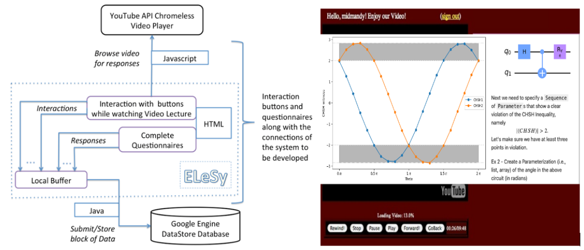

Fig. 2. The architecture of ELeSy (left) and the Interface (right) of ELeSy display the results from CHSH inequality, which is at the heart of the 2022 Nobel Prize for Physics awarded to Alain Aspect, John Clauser, and Anton Zeilinger in part for their pioneering work in quantum information science and for demonstrating violation of CHSH (extension of Bell's) inequalities.

IV. Research Design

The research design consists of four steps and will employ four data collection methods with three groups of students; we will follow the four main steps (see Figure 3). Two experiments will be conducted, one with a traditionally difficult topic and one with a traditionally easy topic of QIS. The classification of "easy" and "difficult" topics is based on our experience teaching QIS and other experts in workforce development, like John Watrous and Sophia Economou. 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 (Jeng et al., 2011, 2013). 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 be evaluated after each lecture using Jupyter Notebooks (with Auto-grader build in) that in long run will support our research towards a personalized "avatar", for future use. In addition, we will use a capstone project at the end of the semester. They will be choose a project/creative activity of interest from a list of projects (the PI will create with them and/or their research advisors) where QIS has the potential to demonstrate quantum advantage (Fox et al, 2020). 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 3 depicts a design flowchart of the longitudinal empirical study.

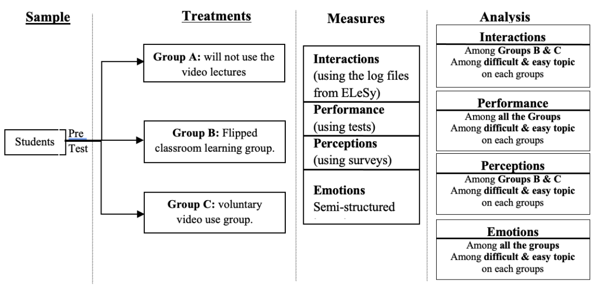

Fig. 3. Graphical representation of the research design of the experiments for each of the traditional easy and difficult QIS topics we will select based on IBM's Lecture notes (John Watrous, 2024) and prior Homework.

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 (Minner et al., 2010). We 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 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 and Shor's 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 (Senk, 1985; Kellman et al., 2010).

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. Gain this multiculturalism perspective is very important (Clark, 2008), 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 (Else-Quest et al., 2008; Else-Quest et al., 2010). In any given term (semester), we anticipate having between N1 to N2 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. In view of the demographics described above, the groups will be balanced based on performance (for required material/classes) and a pre-test. The pre-test will be similar (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 gender. 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. Figure 4 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.

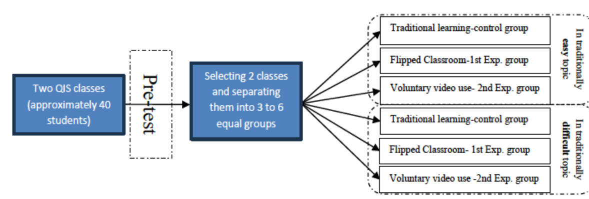

Fig. 4. The formation of the three groups on each one of our experiments.

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 2). 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 (see Appendix A for more information regarding examples of the constructs we will use) (Giannakos and Vlamos, 2013b; Giannakos et al., 2013c; Hsu et al., 2008). 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., Rogers (2004) 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 (Rubin and Babbie, 2009). An interview schedule of three stages, beginning (beg), middle (mid), and end (final), will be used to promote a more focused approach (Polit and Beck, 2005). 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 (Giannakos, Chorianopoulos, Chrisochoides 2015) 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, and 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. For the case of students' perceptions, survey results will be analyzed with 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 (Diawara et al., 2014).

For the case of students' emotions, the basic emotion categories of Oatley and Johnson-Laird (1987) will be used since they have been identified as the main emotions related to computer use (Ngai et al., 2007, Kay, 2012 and Kay and Loverock, 2008). 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 (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. Afterwards, to examine the differences among 1) beg, mid and final phase, 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 Price and Rogers (2004).

For the case of students' mathematical discussions, Scally's (1990) 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 (Ginsburg, 1981). Clinical interviews can also be used to elicit and record students' discussions and thinking in mathematics (Clement, 2000). 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 (in class, online or hybrid, $j = 1, 2, 3$), the k is the k_j^{th} repeated sample observation from the i^{th} student 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 $i = 1, 2, \ldots, a$, a being the number of students in our class, with $j = 1, 2, 3$, and with $k = k_{ij} = 0, 1, .., n_{ij}$.

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 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 with the use of cross-sectional time data. The overall trend can be deduced, and factors related to increases in higher self-efficacy, self-attention, understanding, and ... 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 effects of videos on cognition, social and psychological factors on 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-efficacy, self-attention, understanding, and emotional control will be given. 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. This is necessary since the three groups of students cannot be paired. A GLM with a stepwise selection of the most significant variables will be considered. We hypothesize that videos have greater 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 a 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 intent 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 analysis of the data, 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 take full advantage of the benefits of video lectures. Last, this knowledge will be incorporated into a framework for efficient and innovative development and use of videos to support learning. We will compare the rate of change (increase or decrease) in the impacts cognitive video based on the three groups using the means. This is necessary since the three groups of students cannot be paired. The GLM with stepwise selection of the most significant variables will be considered. We hypothesize that videos have greater 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 after adjusting for the propensity score. However, with large sample sizes, our goal to maximize the predictive capabilities of our models should produce similar results. This will allow us to build the model that explains behaviors after prayer with the minimum error controlling for significant covariates.

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 (Giannakos and Vlamos, 2013b; (Giannakos, Chorianopoulos, Chrisochoides 2015), 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 (Giannakos and Vlamos, 2013a; Giannakos, 2013). 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 (Giannakos and Vlamos, 2013a). However, we found that students (children) generally preferred videos because they felt that it is more fun, easier to use, and more helpful (Giannakos et al., 2013). 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 (Chorianopoulos and Giannakos, 2013). 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 (see Figure 5) 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 (Chorian, Giannakos & Chrisochoides, 2014).

A. Conclusions and Future Work

The purpose of this white paper is to create the infrastructure, so (in the future) we will incorporate live avatar animation in the teaching engagement of our students. Avatars are used for almost everything and can be used to provide and capture real-time facial dynamism and engagement of students. Kellems et al. (2023) proposed using avatars for social interaction compared with humans in children with an autism spectrum disorder. In their findings, on average, the participants exhibited higher social engagement during the avatar sessions compared to lower, stable interaction levels with humans. The use of avatars in QIS teaching needs full exploration, and higher engagement and success should be studied in the online context with the use of animated avatars. The data collected will include eye contact and correct answers to questions asked within a topic session. We are looking at answers that provide a generally appropriate response. Over time, average behaviors (in engagement and correct answers) will be contrasted with the face-to-face in-class students. The team will be able to prepare questions and answers per topic. The avatar will communicate with the participant in real time.

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