Teacher Strategies to Use Virtual Learning Environments to Facilitate Algebra Learning During School Closures

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Abstract

After nationwide school closures due to COVID-19, virtual learning environments (VLE) have seen tremendous increase in usage. The current study identified teacher activities for orchestration using an Algebra VLE during school closures, and whether these activities were related to student achievement. In May 2020, we collected survey data on how 213 teachers were using a VLE for Algebra with 10,590 students, along with system logs and student achievement data. Results indicated that teachers made several changes to teacher strategies due to school closures, including allowing students more time to complete assignments. Multilevel modeling showed that teacher orchestration activities, particularly those related to regulation/management and awareness/assessment, were positively related to student achievement. We discussed the results and provided implications for practice (Q&A setting, assignment flexibility).

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Virtual learning environments (VLEs) have become a common resource for teachers to supplement classroom instruction in mathematics, and school districts frequently pay for subscriptions to VLE and push teachers to use them. There is evidence in the literature that the use of VLEs to supplement classroom instruction can increase students learning (Mitten et al., 2021; 2019; Roschelle et al., 2016). Furthermore, many studies have examined specific activities to supplement classroom teaching with VLE to improve teaching and learning in K-12 settings: some studies focused on activities for completely in-classroom use of VLE (Fong et al., 2018; Jones & Warren, 2011; Veletsianos & Navarrete, 2012); other research focused on supplementing classroom teaching with VLE more in line with blended learning, thus combining online educational materials and opportunities in VLE with traditional place-based classroom methods (Martin et al., 2016; Schwier et al., 2009; Wang et al., 2017). More importantly, due to the COVID-19 pandemic, schools moved instruction online during the Spring of 2020, and VLE platforms had a tremendous increase in usage (The World Bank, 2020). The increasing use of VLE presents a unique opportunity to investigate possible relationships between how teachers orchestrate their student's engagement with these VLE during a crisis time. Therefore, the objective of this study is to identify teacher activities for use of VLE that had a positive relationship to student learning during extended school closures due to COVID-19. The identification of effective activities is critical in better preparing educators for future temporary school closures.

Plenty of research addresses how to best deliver teaching and learning entirely online (DiPietro, 2010; Lee et al., 2014). However, scholars have illustrated the grand difference between carefully designed online learning versus emergency remote teaching (Bozkurt & Sharma, 2020; Hodges et al.,

2020). While the prior takes months of planning, preparation, and development time for a completely online course, the latter is a quick temporary shift of instruction to an alternate delivery mode due to crisis circumstances. The teaching and learning activities for well-planned online courses may not work effectively for emergency remote teaching (Hodges et al., 2020). A few studies examined how countries respond to school closures in a time of crisis at a national level (Davies & Bentrovato, 2011; Rajab, 2018) and how students reacted to the move to online learning due to the COVID-19 pandemic (Yan et al., 2021), but there is a scarcity of studies about emergency remote teaching and learning activities. As VLE naturally becomes an integral part of solutions to emergency remote teaching, it is imperative for educational researchers to study and provide guidance on how teachers should orchestrate VLE to facilitate learning and students' use of VLE and be prepared for future crises.

Theoretical Framework

Teacher Orchestration

The main theoretical perspective that informs our investigation of teaching and learning with the facilitation of VLE is the framework of orchestrating learning (Prieto et al., 2011). Orchestrating learning is particularly useful as an analytical lens when researching technology enhanced learning settings to structure the information available to the researchers, and to detect challenges and eventual solutions to aid teaching and learning in these settings (Dillenbourg, 2013). Dillenbourg operationalized orchestration as "how a teacher manages, in real time, multi-layered activities in a multi-constraints context" (2013, p. 485). To provide a more comprehensive definition of orchestration, Prieto (2012) operationalized it as the process to design, manage, adapt, and assess learning activities by teachers and other actors. In the process, teachers utilize available resources to maximize learning effect both theoretically and pragmatically to adapt to contextual constraints. The framework on orchestration by Prieto et al., allows for broader research inquiries on technology-enhanced environments and has been widely examined by researchers to effectively support the development and evaluation of technology-

integrated learning interventions (e.g., Munoz-Cristobal et al., 2014; Prieto et al., 2015; Rodríguez-Triana et al., 2015).

The framework of Prieto et al. will guide our analysis and understanding of teaching and learning activities from five distinct aspects: (1) Design: a critical component of orchestration is planning the learning activities, often referred to as learning design (Koper & Tattersall, 2005). Learning design emphasizes the use of pedagogical tools, either paper-and-pencil or digital, to design and develop learning activities (Holmes et al., 2019). There is an even greater need in technology enhanced learning settings for adequate planning and designing of the activities and technological tools so that the objectives of a learning activity can be achieved. (2) Regulation/management: a significant aspect of many works on orchestration is the regulation of learning activities, either external regulation from teachers or students' self-regulation (Dillenbourg, 2009). Issues related to class, time, workflow, group management can also be gathered under this theme. (3) Adaptation/flexibility: It is the act of changing and adapting the design/plan to the local context of the classroom and the emergent occurrences during the enactment of learning activities. The aspect of adaptation/flexibility often requires the management of learning activities as well. (4) Awareness /assessment: teachers' awareness of what is happening in the context and within the learners' minds through various strategies (e.g., formative assessments, learning progress monitoring, inquiries with students). Assessment can provide insight into the progress towards the intended learning outcomes. An important source of data to investigate teachers' activities for awareness/assessment in VLE is teachers' logs, with which numerous studies have shown the effectiveness on understanding such orchestration activities (e.g., Martinez-Maldonado et al., 2013; Van Leeuwen, 2015); (5) Roles of teachers and students: The research work on orchestration centers mainly on the perspective of teachers, where teaching presence is critical to achieve orchestration (Kennewell et al., 2008). However, nothing precludes the learners themselves from using the concepts presented above. In fact, there is a range of possibilities for learners to play a key role in orchestrating learning where

learners directly affect the awareness mechanism (Alavi et al., 2009), or scenarios where only the widest goals and activities are set by the teacher, and the learning tasks and their coordination are handled by the students (e.g., in a problem-solving environment). Similarly, this conceptual framework and particularly its five aspects will guide us to analyze and understand the different teaching strategies of students with the facilitation of VLE and students' use of VLE in the context of COVID-19 crisis.

This study's research goal is to identify teacher activities for orchestration of instruction under the five strategic aspects of Prieto et al. using an Algebra VLE during school closure, and to evaluate whether certain combinations of teacher activities are positively related to student achievement. The current study addressed the following research questions:

1. What changes did teachers make to re-orchestrate their instruction with the VLE after schools closed?
2. Did the changes performed by teachers after schools closed differ between teachers who taught synchronously and asynchronously?
3. What aspects of teacher orchestration of the VLE could predict student achievement?

Methods

Setting

For this study, we focused on the Math Nation VLE (Lastinger Center for Learning, University of Florida, 2022), formerly Algebra Nation, which is currently available to students in five states of the United States. We focused on Florida, where it is widely used by students and teachers to assist in classroom instruction, and where there is evidence that the use of the VLE is associated with increased student achievement (Leite et al., 2019, 2021; Mitten et al., 2021; Niaki et al., 2019). It is integrated with the school districts' online platforms so that students and teachers can log in using the same id and password they use for other district-level online services. The VLE contains 10 sections for 9 major algebra domains (e.g., linear equations, quadratic equations), and each section is divided into 6 to 12

topics, for a total of 93 topics. These topics are aligned with the state mathematics standards. For each topic, an instructional video is available in multiple versions from tutors that are heterogenous with respect to gender and ethnicity, and with varying instructional styles. There are short 3-question quizzes for each topic, and 10-question assessments at the end of each section. Finally, solution videos for each question in the 10-question assessments become available once the student completes an assessment. A previous survey of teacher users of this VLE indicated that the majority of teachers show the VLE videos to the whole classroom, reserve time during class for students to work individually on the VLE, use the VLE workbook during class, and assign both videos and quizzes as homework (Mitten et al., 2021).

Sample

We obtained data from two sources: 1) logs of student and teacher use of the VLE and student test scores; 2) Data from a teacher survey collected during the school closure. The teacher survey was administered online between May 21st and June 1st by showing a pop-up screen to teachers who logged in into the VLE system. The population of teachers who use the VLE includes approximately 6,000 teachers annually. The survey resulted in 349 valid responses, which were used to address Research Question 1. Because data was collected from those who logged in into the VLE during this specific period, it is not a random sample of teachers that is representative of the population, but it does offer a window into teacher practices during the COVID-19 pandemic. From the teachers included, 139 (39.8%) were teaching asynchronously, and 210 (60.2%) were teaching synchronously at least some of the time. Of these, 88% had never taught online, 3% taught online just once, and 9% taught online multiple times before school closures. After selecting teachers who had an active record in the VLE during the Spring 2020 semester, Research Question 2 was addressed using a sample of 213 Algebra 1 teachers and their 10,590 middle and high school students.

Measures

The outcome of interest is student Algebra achievement in 9 domains, which was measured by a 10-question test yourself (TYS) assessment for each domain. The TYS assessments are part of the VLE, which also contains a solution video for each question of the TYS. The domains covered by the TYS are: 1) expressions, 2) equations and inequalities, 3) introduction to functions, 4) linear equations, functions and inequalities, 5) quadratic functions, 6) exponential functions, 7) summary of functions, 8) one-variable statistics, 9) two-variable statistics. The items of the TYS were designed to match those items that students see in the high-stakes Algebra test required by the state for high school graduation. A psychometric evaluation of the TYS was performed using item response theory in a previously study (Xue et al., 2021). For the current study, the number of correct answers to each TYS was used as the outcome.

Two types of indicators of teacher orchestration strategy were used: the first type are responses to the teacher survey. The survey was aligned with the framework of orchestrating learning (Prieto et al., 2011). It included questions about which resources and activities were used by teachers to teach Algebra before and during school closure, and the role that the VLE played in their instruction[1]. We designed questions in the survey to unravel teachers' activities under the five strategic dimensions of orchestration from Prieto et al (2011). The survey included a combination of single-select and multiple-select questions.

The second type of orchestration indicators were created from aggregating logs of the VLE teacher accounts. We used the timestamps when assessments were taken as the cut-off points for log aggregation. For example, if an assessment was taken by a student on March 8th, 2020, then the logs of the student's teacher would only be aggregated up to that day. We first aggregated teachers' logs as count data (e.g., number of times teacher checked students' leaderboard), which were then standardized

[1] The complete survey is available in the Open Science Framework site (https://osf.io/p2jrb/)

as continuous values in preparation for multilevel regression models. While more than 40 actions were recorded as logs in Math Nation, some of them were student-specific. Eventually, we kept 27 of the log actions in the dataset based on whether at least one teacher participant has initiated a specific action throughout the target period.

Analysis

To address the first research question, we present a descriptive statistical analysis of the results of the teacher survey. To address the second research question, we asked teachers how many synchronous or asynchronous sessions they conducted per week for each class (see Table 1). We dichotomized this variable into either holding any synchronous classes or teaching completely asynchronously. With this dichotomized variable, we ran chi-square tests for independence to assess whether there were group differences in survey responses frequencies between teachers teaching synchronously or asynchronously. We also conducted chi-square tests on questions where teachers were asked about their behaviors before and after school closures.

To address the third research question, we fit a three-level multilevel model (i.e., hierarchical linear model or mixed effects model; Snijders & Bosker, 2012) to predict student achievement with teacher orchestration indicators obtained from both the survey and system logs. The three-level data structure consists of responses to each TYS assessment (level 1, n = 85,924) provided by students (level 2, n = 10,590), which are clustered by teachers (level 3, n = 213). The mean number of assessments per student was 8.11 from a total of 9 domain-specific TYS assessments available in the VLE. The mean number of students per teacher was 49.17, which is larger than the typical Algebra 1 class size because the data included all classes from each teacher. The level-2 intraclass correlation was 0.458, indicating that 45.8% of the score variance was among students within teachers. The level-3 intraclass correlation was 0.216, indicating that 21.6% of the score variance was among teachers.

The three-level model was specified according to the following equation:

$$y_{ijk} = \gamma_{000} + \sum_{l=1}^{L} \delta_l x_{lk} + \sum_{m=1}^{M} \pi_m z_{mk} + u_k + r_{jk} + e_{ijk} \quad (1)$$

where y_{ijk} is TYS number-correct score for domain i, student j and teacher k, γ_{000} is an intercept, δ_l is the coefficient of predictor x_{lk} from the teacher survey, π_m is the coefficient of predictor z_{mk} from the teacher system logs, $u_k \sim N(0, \rho^2)$, $r_{jk} \sim N(0, \upsilon^2)$ are teacher and student random effects, respectively, and $e_{ijk} \sim N(0, \zeta^2)$ is the level-1 residual.

The multilevel model was estimated using maximum likelihood estimation with the *lme4* package (Bates et al., 2015) of the R statistical software (version 4.0)[2]. We fit the multilevel model in Equation 1 twice: In the first model fit, we included all 27 system log predictors and 70 survey predictors. These predictors were created from the survey questions design to capture the elements of teacher orchestration in Prieto et al.'s (2011) framework. Multiple choice questions in the survey were turned into dummy-coded variables, while mark-all-that apply questions were converted to a series of binary (i.e., zero/one) variables. However, multicollinearity among the predictors may substantially bias standard errors of coefficient estimates (Yu et al., 2015). To investigate this problem, we used the results to calculate the variance inflation factor (VIF) for the predictors. We found out that there were strong degrees of multicollinearity between some of them, with a mean VIF of 3.6 and maximum of 36. We then fit the model with only covariates with VIF < 2.5, which included 13 system log predictors (see Table 4) and 44 survey predictors (see Table 5). We noticed that the number of statistically significant coefficients increased substantially from the first model to the second model, and therefore we report the results of the second model.

INSERT TABLE 1 ABOUT HERE

[2] The code for model estimation is available in the Open Science Framework site (https://osf.io/p2jrb/)

Results

Teacher Survey

Overall results indicate that many teachers made a variety of changes to their teacher practices as a result of school closures. There were few differences in responses between teachers teaching synchronously and asynchronously, with some notable exceptions. Whenever the test for differences between synchronously or asynchronously teaching was not statistically significant, we present results across both groups. The survey results shown below[3] are organized into subsections, based on the five dimensions of the orchestrated learning framework (i.e., Design, Regulation/Management, Adaptation/Flexibility, Assessment/Awareness, and Roles of Students and Teachers) described in detail earlier (Prieto et al., 2011).

Design

Within the design component of teacher orchestration, chi-square tests indicated no differences between teachers teaching synchronously or asynchronously for questions on how the teaching of algebra had been impacted by the Spring 2020 school closures (χ^2 (3, n =348) = 4.0356, p = 0.2303). Nearly all teachers allowed for extra time for students to complete assignments (93.6%), and most reduced the number of assignments (77.4%). Most also noted that students asked fewer questions (74.9%). However, few teachers indicated that they stopped introducing new material (12.3%), or that each lesson was less structured (28.8%). After schools closed, the majority of teachers reported being able to plan lessons at least 3 days in advance (82.6%). Therefore, school closures did not create a situation where teachers had little to no time to plan their lessons in advance.

[3] Supplemental survey tables are available in the Open Science Framework site (https://osf.io/p2jrb/)

Regulation/Management

Differences between teachers teaching synchronously versus asynchronously were present in how deadlines were established for completing assignments (χ^2 (2, n = 347) = 12.161, p = 0.0023), with the results indicating that teachers teaching asynchronously gave students more time to complete assignments than teachers teaching synchronously. For teachers holding asynchronous classes, a majority (56.5%) gave students more than one week to complete assignments, while 37.8% of teachers teaching synchronously did so. Across all teachers, this response was the most selected (45.2%). A higher percentage of teachers teaching synchronously allowed either one or two days to complete assignments (16.3%) or three days to one week (45.9%) in comparison to those teaching asynchronously (i.e., 9.4% for one or two days, and 34.1% for three days to one week).

When asked about routines used to address student questions since schools closed, students e-mailing questions was the predominant response (86.7%), followed by students sending questions in the chat area (66.6%). These categories are not mutually exclusive, as teachers were allowed to select more than one. However, a substantial number of teachers (51.9%) also indicated that they used another method not listed in the survey.

Adaptation/ flexibility

A chi-square test detected no group differences between asynchronous and synchronous groups in the frequency of skipping or condensing content. Nearly half of all teachers (48.5%) indicated that they had to skip content after schools closed, while about 40% condensed content. Slightly fewer (38.1%) kept content as planned.

Awareness/ Assessment

Two survey questions were related to the awareness/assessment component of teacher orchestration before and after school closures. Statistically significant differences between teacher behavior before and after school closures were found in responses (χ^2 (9, n = 343) = 81.6, $p < 0.001$).

The proportion of teacher requiring quizzes or tests once or twice a week fell from 48.4% of teachers before schools closed to 37.9% of teachers after closure. The proportion of those requiring tests less than once a week rose from 44% to 51.6%, and those requiring quizzes or tests more frequently than three times a week also increased from 7.6% to 10.5%. The change of quiz weekly frequency indicated that more than three or less than one quiz or test became more common after schools closed, and once or twice became less common. However, when looking at group differences between asynchronous and synchronous teaching after schools closed, a chi-square difference test detected no differences between the two groups (χ^2 (3, n = 343) = 2.269, p = 0.5186). Findings were similar when asked if students were allowed to redo incorrect problems: a higher proportion of teachers allowed for this after school closures (88.1%) compared to before (78.4%); χ^2 (1, n = 343) = 45.412, p = < 0. 001. However, chi-square difference tests detected no difference in allowing students to re-do incorrect problems from before to after school closures between synchronous and asynchronous groups (χ^2 (1, n = 343) = 0.60783, p = 0.4356).

Roles of teachers and students

For a question asking about teacher confidence levels to deliver effective remote teaching, the most frequent response was "Moderately confident" (43.7%) followed by "Slightly confident" (25.9%). There was no difference between teachers in synchronous or asynchronous teaching settings (χ^2 (3, n = 343) = 5.1899, p = 0.1584). When asked about technology problems that affected them during the Spring 2020 (see Table 2), a majority of teachers did not experience any of the technological issues during school closures. The most frequently cited issue experienced by teachers was "I could not log in to the online system I needed." When combining categories, 45.9% of teacher experienced this issue at least once, however most of them experienced the issue less than once per month. Over 10% of respondents noted other computer problems that they experienced at least once per week. Among technology issues, group differences were detected for the question "I was not able to log in to an online

meeting." While 81.6% of teachers with asynchronous courses reported no issues with logging in to online meetings, only about two-thirds of teachers with synchronous courses reported no issues. This difference may be due to teachers with synchronous classes having to join online meetings more frequently than teachers teaching asynchronously. In all other technological issues surveyed, chi-square difference tests did not detect any differences between synchronous and asynchronous teaching groups.

With respect to previous experience teaching online, a large majority of teachers had never taught online before school closures (87.8%), while 3.5% had taught online once, and 8.7% had taught online multiple times. A chi-square difference test indicated no differences between teachers teaching synchronously and those teaching asynchronously on their experience teaching online before school closures (χ^2 (2, n = 345) = 4.0779, p = 0.1302).

INSERT TABLE 2 ABOUT HERE

Students enrolled in the first Algebra course in public schools in Florida are expected to take the Algebra 1 End of Course (EOC) assessment at the end of the academic year (Florida Department of Education, 2022). The EOC exam is a high-stakes test required for graduation, but it was cancelled by the state's governor in 2020 due to the pandemic. With respect to perceived impacts of the cancellation of EOC exam (see Table 3), teachers indicated that student time and dedication to algebra either stayed the same (40.1%) or decreased (48.4%), with very few stating that this increased (11.6%). Similar responses were given for student interest in algebra, with just 4.2% viewing that interest in algebra increased, while nearly half (49.9%) noted that interest decreased, and 46% that it stayed the same. However, more teachers viewed that they had more flexibility to plan lessons (56.2%) as a result of the

cancellation of the Algebra I EOC exam. Teachers also largely believed that the alignment between assessments they gave and the cancelled Algebra I EOC did not change (77.1%).

INSERT TABLE 3 ABOUT HERE

Prediction of Student Achievement

We fit the multilevel model shown in Equation 1 to identify the relationships between student achievement and measures of teacher orchestration, obtained from the teacher survey and from the VLE system logs. The standardized coefficients for the predictors obtained from the system logs, which refer to teacher behaviors captured by the VLE, are shown in Table 4. We found that most of these teacher behaviors were positively related to student achievement, showing that teacher preparation and monitoring of students in the VLE platform predicted how well their students performed on the TYS assessments. The largest standardized coefficient was for "Toggle video captions," which is a regulation/management dimension of orchestration. This result indicates that each standard deviation increase in the frequency of teachers making captions available to students is associated with an increased in 0.338 standard deviations in student achievement. Teachers searching discussions and watching assessment review videos also had standardized coefficients higher than 0.25, indicating that they were highly associated with student achievement. Searching discussions and watching assessment review videos were related to the awareness/assessment dimension of orchestration. All components related to teachers reviewing Algebra content in the VLE (i.e., complete previous TYS quiz, watch assessment solution videos, watch assessment review videos, and view learning/teaching materials) were positively associated with student achievement. However, such an association was not true for most behaviors related to teachers reviewing non-Algebra content parts of the VLE. More specifically, "Click

profile pictures" was negatively associated with student achievement, while "watch orientation videos," and "watch lecturers' bio videos" were not associated with student achievement. From the non-Algebra content, only "loading orientation page" was positively related to student achievement, possibility due to its relation to the regulation/management aspect of orchestration. Surprisingly, "Post/reply discussions," which is part of the awareness/assessment dimension of orchestration, was also not related to student achievement.

INSERT TABLE 4 ABOUT HERE

The standardized coefficients from the predictors obtained from the teacher survey are shown in Table 5, grouped by the teacher orchestration dimensions they are related to. Most of teachers' responses to the survey questions were not associated with student achievement. However, the predictors "Address questions by students raising hand during live online teacher session," "Evaluate student learning with Canvas quizzes," "Evaluate student learning with Performance Matters," and "Frequency of Requiring students to complete a quiz before schools closed" were positively related to achievement.

Within the awareness/assessment dimension of orchestration, we found significant coefficients associated with the use of Performance Matters and Canvas. In fact, those were the largest coefficients from all survey variables in the model. Performance Matters is a software company that provides online assessments and learning analytics to schools. Canvas is a learning management system (LMS) used by schools, where teachers can implement online versions of their own assessments. These coefficients show positive relationships between use of these tools and student achievement, but they cannot be

interpreted as causal effects, as this is a non-experimental study, and the relationship between the use of these systems and student achievement may be confounded by other dimensions of orchestration. We found that coefficient of the frequency of requiring students to complete a quiz or test before schools closed statistically significant. Because the frequency of requiring a quiz was coded so that a higher number indicates teachers that give quiz more frequently during the week, the positive coefficient indicates that teacher increased use of quizzes is associated with higher student achievement. Taken together, these coefficients indicate the importance of assessment/awareness dimension of orchestration with respect to predicting student achievement.

A few survey predictors were negatively related to student achievement. These were "Give more grades for effort" and "Call students not completing assigned work," which were prompted by the question "How has your teaching of Algebra been impacted by the current school closure?" Teachers who indicated that they performed these changes had students who performed lower in the TYS assessments than teachers who did not perform these changes.

INSERT TABLE 5 ABOUT HERE

Discussion and Conclusion

After nationwide school closures due to COVID-19, VLE have seen tremendous increase in usage. There are studies examining the delivery of instructions in VLE entirely online (DiPietro, 2010; Lee et al., 2014), while a gap exists between carefully designed online learning versus emergency remote teaching (Bozkurt & Sharma, 2020; Hodges et al., 2020). To the best our knowledge, few studies have examined emergency remote teaching and learning activities in VLE. To better prepare future teaching and learning in VLE in the case of emergency, this study aimed to investigate and reveal

teachers' instructional activities during school closure and their effects on student achievement through the lens of teacher orchestration by Prieto et al. (2011). Specifically, we demonstrated descriptive statistics and conducted statistical tests on 213 teachers' survey responses on orchestration activities before and after school closure. We then conducted multilevel modeling on students' achievement of these teachers ($n_{student}$ = 10,590) using teachers' survey responses and logs as orchestration indicators. The following sections discussed the interpretations of the results and the implications for future practice.

RQ1: Orchestration Activities Before vs. After School Closure

The Covid-19 pandemic was a particularly challenging time with respect to teacher preparation for instruction because the majority reported having never taught online. Some had to quickly identify activities to teach synchronously, others had to prepare to teach asynchronously. Interestingly, most (89.4%) reported at least some confidence in their ability to deliver instruction online. Answering the first research question, the results of the survey indicate that teachers adapted their orchestration activities in different ways to deal with the context of schools being closed and delivery of instruction online. In general, teachers' orchestration activities after school closure tended to allow for more flexibilities in learning design (e.g., extra assignment time), adopt remote regulation and management approaches (e.g., addressing Q&A with emails and discussion forums), adjust instructional pacing (e.g., condensing learning content), and ease on using formative assessments as learning checkpoints (e.g., less than one quiz per week).

RQ2: Teachers Teaching Synchronously vs. Asynchronously

With respect to the second research question, the only difference identified between teachers teaching synchronously and asynchronously was with respect to the time allowed to complete assignments. The fact that there was only a single significant strategy differences between teachers who taught asynchronously and synchronously suggests that the adapted orchestration activities might have

been stimulated by the context change instead of the instruction delivery format. The most salient information gathered from the survey is that teachers increased the allotment of time for student activities, while making these activities shorter. These results show that teachers may have recognized the difficulty of the new learning context created by the COVID-19 pandemic, and possibly assumed that students would not do as well in the new context. Such an assumption has been found to be effective for students' learning in the study of Gandasari and Dwidienawati (2020), where the researchers concluded that being flexible on students' time-on-task was recommended to help students adapt to the sudden change of contexts.

RQ3: Teacher Orchestration vs. Student Achievement

With respect to the third research question, the results of the multilevel regression model showed that the more teachers were actively involved in monitoring and planning with the VLE platform, which aligns with the regulation/management dimension of teacher orchestration, the better their students performed on assessments within the platform. Such a phenomenon is expected as studies have found students' performance is positively related with teachers' facilitations (Akhtar et al., 2017; Régner et al., 2009). The multilevel model also indicated that practice on assessments outside of the VLE, such as in Canvas or Performance Matter platforms, were associated with increased student achievement. Given the correlational nature of the study, this does not provide any information about relative effects of different assessment platforms, but it does show that the use of awareness/assessment orchestration activities by the teacher is associated with student achievement. Finally, some activities to reduce the pressure on students, such as assigning more grades for effort, were negatively associated with student achievement. While students' effort is an aspect of engagement that positively influences achievements, the grading of it can be subjective (Kunnath, 2017). Students' procedural effort (e.g., simply following teachers' instruction) can be falsely graded as substantive effort (e.g., critical thinking), where the former has been found to bear limited meaningful implications for students' growth and the latter is

more closely related to students' achievements (Kelly, 2008). In this study, further investigation is needed to understand teachers' grading scheme on effort to better interpret the result.

Implications for Practice

Several orchestration activities have been identified in this study that can be potentially adopted by teachers in virtual learning environments during a time of emergency. First, teachers may utilize synchronous sessions to directly address Q&A to better support students. While there are multiple channels to conduct Q&A with students (e.g., emails and asynchronous VLE chat area), the multilevel regression model showed that only "address questions by students raising hand during live online teacher session" was positively associated with students' achievement. This can be explained in two ways: On one hand, this form of instruction provides students with direct teaching presence, helps mimic what is available in a physical classroom that students are familiar with, and thus can help students adapt to the use of VLE (Le & Truong, 2021). On the other hand, students sharing their thoughts in front of their classmates can enhance their social presence and create a sense of belonging in the VLE, which can better engage them with the new context (Palloff & Pratt, 2007). In contrast, emails and chat areas can be inefficient in addressing complex or follow-up questions due to their written communication format and asynchronous nature (Duncan et al., 2012), showing no significant effects on students' achievements.

Second, teachers may consider making assignments more flexible than usual. It is worth noting that teachers' flexibility on extra time and reduced number of items in assignments did not have effects on students' achievements. This might be explained that students did not have sufficient practice to internalize learned concepts and connect them with prior knowledge, which is important for math achievement (Fernández-Alonso et al., 2015). However, students' learning success is not solely dependent on academic achievements, where their motivation and engagement to learn can also be important (Steinmayr et al., 2019). Studies have suggested that allowing more flexibility in assignments

can help improve students' engagement and better adapt to an unexpected situation change (e.g., Mahmood, 2021).

Third, teachers may leverage technology-enhanced platforms to assist with assessments. Compared to evaluating students outside of learning platforms, which has no effects on students' achievements, students of teachers who adopted Canvas or Performance Matters for assessments tended to have increased achievements. The difference might be explained by the analytical and well-structured features available in technology-enhanced learning platforms to support teaching and learning. However, it is interesting to see that using Kahoot or IXL did not contribute to students' achievements. The non-significant associations of Kahoot and IXL use compared to Canvas and Performance Matters use might be related to numerous factors that need further investigation. For example, the effectiveness of gamification (a highlight in Kahoot) can be subject to how teachers integrate gamification in class (Jagušt et al., 2018) and students' individual differences (Stoyanova et al., 2017). Meanwhile, the fixed question banks without custom contributions from teachers in IXL can make students feel decontextualized (Resnick & Resnick, 1992), resulting in a non-significant effect.

Finally, teachers are advised to keep track of students' learning progress in non-intruding ways. Results have shown that calling out students who did not complete assignments can have a significant negative effect on students' achievements as students might feel their personal lives have been affected. However, the analysis of teachers' log data on the VLE suggests that a close monitoring of students' learning progress with learning analytics can effectively support students' learning. This implication can be supported by the significant positive effects of the frequency of checking students' learning progress (Load students leaderboard) and checking students' discussion activities (Search discussions). Similar findings have also been found in other studies on learning analytics tools, where both teachers and students can benefit from such tools. For example, Mavrikis et al. (2019) created a suite of learning analytics tools to help teachers understand students' learning progress in virtual environments for math

learning. The researchers recruited 26 pre-service math teachers and collected their opinions on the tools. A majority of the participants expressed great perceived usefulness towards the tools. In the study of Gašević et al. (2016), the researchers showed and discussed how students could benefit from a system that informed teachers of students' learning status.

Limitations

Several limitations exist in this study. First, although the current study provides a window into the practices adopted by teachers during the period of school closure, it does not provide in-depth information about their practices. Follow-up research using qualitative methods would allow for a deep understanding of the teachers' motivations and orchestration activities during this difficult period of their careers. Second, while students' achievement is an important factor to understand the consequences of teacher's choice of activities, other factors may contribute to such understandings, such as self-efficacy and motivation, that were omitted from the current study. Future research that incorporates more student indicators can provide a more thorough evaluation of teachers' orchestration activities. Third, although the associations between teacher orchestration practices and student achievement identified in the current study are supported by existing theory, this study does not provide causal evidence for the effects of teacher orchestration on student achievement. Such evidence is needed from experimental and quasi-experimental studies of teacher orchestration. Finally, the results of the study suggest that teachers' use of other learning platforms such as Canvas and Performance Matters is positively associated with students' achievement. However, only log data on the VLE was available in this study and no further investigation was conducted with other learning platforms. Future studies can better illuminate how teachers' orchestration activities were interacted on learning platforms serving different purposes (e.g., assessment-focused vs. content-focused).

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Table 1. How frequently do you conduct synchronous online meetings for each class (all categories)?

Response category	n (%)
Once per week	75 (21.5%)
Twice per week	63 (18.1%)
Three times per week	21 (6.0%)
Four times per week	15 (4.3%)
Five times per week	36 (10.3%)
I do not use synchronous online meetings	139 (39.8%)
Total	349 (100%)

Table 2. Teacher responses about the extent that technology issues happened to them since schools closed

Technology-related problems	At least once each week (%)	At least once this month (%)	At least once since schools closed (%)	This issue did not happen (%)	Chi-sq.
I was not able to log in to an online meeting	12 (3.5%)	23 (6.7%)	58 (17.0%)	249 (72.8%)	9.092*
Asynchronous	*4 (2.9%)*	*6 (4.4%)*	*15 (11.0%)*	*111 (81.6%)*	
Synchronous	*8 (3.9%)*	*17 (8.3%)*	*43 (20.9%)*	*138 (67.0%)*	
I could not log in into the online system I needed	22 (6.5%)	37 (10.9%)	97 (28.5%)	184 (54.1%)	2.207
I could not find the online resource I needed	16 (4.7%)	23 (6.8%)	59 (17.4%)	242 (71.2%)	6.662
I had other computer problems	37 (10.9%)	34 (10.0%)	86 (25.4%)	182 (53.7%)	0.871

*Note: n = 339; * p<0.05; ** p< 0.001*

Table 3. In your view, how did the cancellation of the Algebra I End of Course (EOC) assessment impact you and your students?

Area of impact	Increased (%)	Stayed the same (%)	Decreased (%)
Student time and dedication to Algebra	39 (11.6%)	135 (40.1%)	163 (48.4%)
Student interest in Algebra	14 (4.2%)	155 (46.0%)	168 (49.9%)
Your flexibility to plan lessons	189 (56.2%)	126 (37.5%)	21 (6.2%)
The alignment between the assessments you gave and the Algebra 1 EOC	11 (3.3%)	259 (77.1%)	66 (19.6%)

Table 4. Standardized Coefficients of Predictors of Student Achievement from Teacher System Logs

Predictor	Estimate (SE)
Complete previous TYS quiz	0.195 (0.023)***
Load orientation page	0.157 (0.035)***
Watch orientation videos	-0.086 (0.056)
Load students leaderboard	0.126 (0.032)***
Search discussions	0.276 (0.050)***
Watch assessment solution videos	0.141(0.031)***
View assessment correct answers	0.013 (0.022)
Watch assessment review videos	0.265 (0.064)***
Post/reply discussions	0.002 (0.037)
Watch lecturers' bio videos	0.040 (0.096)
View learning/teaching materials	0.212 (0.032)***
Toggle video captions	0.338 (0.079)***
Click profile pictures	-0.622 (0.097)***

Table 5. Standardized Coefficients of Predictors of Student Achievement from Teacher Survey Responses

Dimension of orchestration targeted	Predictor	Estimate (SE)
Design	Change practice to allow extra time to complete assignments	0.654 (0.451)
	Change practice to reduce number of assignments	0.043 (0.282)
	Change practice to make assignments shorter	-0.203 (0.228)
	It takes more time for students to ask questions	0.164 (0.232)
	Students ask fewer questions	0.096 (0.248)
	Give more grades for effort	-0.556* (0.230)
	Each lesson is less structured	-0.033 (0.247)
	Teacher stopped introducing new material	-0.413 (0.320)
	Teacher created custom assignments in the VLE	0.050 (0.138)
	Teacher assigned practice problems in other platforms	0.080 (0.159)
	Teacher assigned assessments in other platforms	-0.065 (0.141)
	Extent teacher planned lessons in advance	0.129 (0.126)
Regulation/Management	Method of establishing deadlines for completing assignments	-0.272 (0.150)
	Address questions by students raising hand during live online teacher session	0.545* (0.239)

	Address questions by students sending questions on a chat area of online meeting platform	-0.391 (0.234)
	Address questions by students sending emails	0.531 (0.311)
	Address questions by other methods	0.271 (0.224)
	Email students not completing assigned work	0.035 (0.378)
	Message students in classroom management system for students not completing assigned work	0.380 (0.294)
	Call students not completing assigned work	-0.513* (0.251)
	Using another contact method for students not completing assigned work	-0.167 (0.237)
Adaptation/Flexibility	Student access to algebra textbook to study algebra	0.415 (0.239)
	Student access from non-workbook printed materials from Algebra Nation	-0.376 (0.267)
	Student access to printed materials from another source	0.251 (0.301)
	Used Algebra Nation reports to reteach topics/ concepts: Before schools closed	-0.144 (0.222)
	Used Algebra Nation reports to assign customized homework: Before schools closed	-0.105 ()0.280
	Used Algebra Nation reports to assign videos to individual students: Before schools closed	-0.151 (0.265)

	Used Algebra Nation reports to reteach topics/ concepts: After schools closed	0.204 (0.224)
	Used Algebra Nation reports to assign customized homework: After schools closed	-0.122 (0.271)
Awareness/Assessment	Evaluate student learning with questions in Algebra Nation	0.026 (0.261)
	Evaluate student learning with Canvas quizzes	0.625* (0.257)
	Evaluate student learning with Kahoot	-0.215 (0.318)
	Evaluate student learning with Performance Matters	0.745** (0.272)
	Evaluate student learning with IXL	0.041 (0.273)
	Evaluate student learning with assessments in other online learning platforms	0.132 (0.214)
	Evaluate student learning with another method not in an online learning platform	0.178 (0.273)
	Frequency of requiring students to complete a quiz or test: Before schools closed	0.305* (0.151)
	Frequency of requiring students to complete a quiz or test: After schools closed	-0.087 (0.156)
	Allowed students to redo incorrect problems: Before schools closed	0.129 (0.275)
	Allowed students to redo incorrect problems: After schools closed	-0.251 (0.317)

Roles of students and teachers	Teacher confidence to deliver effective remote teaching	-0.030 (0.115)
	Experience teaching online before schools closed	0.097 (0.173)
	Teacher perception of cancellation of Algebra I EOC exam on flexibility to plan lessons	-0.081 (0.181)
	Teacher perception of cancellation of Algebra I EOC exam on alignment of assessments given and EOC	0.425 (0.243)