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Exploring the Creation of Instructional Videos to Improve the Quality of Mathematical Explanations for Pre-Service Teachers

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Abstract: One of the primary skills required by mathematics teachers is the ability to provide effective explanations to their students. Using Kay's (2014) theory-based framework for creating instructional videos, this study explored the quality and growth of explanations embedded in mathematical instructional videos created by 37 pre-service teachers (female = 26, male = 11). The Instructional Video Evaluation Scale (IVES), comprised of four constructs (establishing context, explanation heuristics, minimizing cognitive load, engagement), was used to assess the quality of two videos (pre-feedback and post-feedback). The initial video created by pre-service teachers (pre-feedback) revealed a number of problem areas, including providing a clear problem label, using visual supports, noting potential errors that might occur, writing legibly, highlighting key areas, listing key terms and formulas, being concise, and using a clear, conversational voice. After receiving detailed feedback based on the IVES, the ratings of the second video (post-feedback) for each of the initial problem areas increased significantly. The IVES scale, grounded on Kay's (2014) framework, helped identify and improve the effectiveness of pre-service teachers' explanations of mathematics concepts.

Keywords: pre-service teachers, instructional videos, mathematics teaching, explanation

Résumé: L'une des principales compétences requises des professeurs de mathématiques est de fournir des explications efficaces à leurs élèves. À l'aide du cadre théorique de Kay (2014) pour la création de vidéos pédagogiques, cette étude a exploré la qualité et la croissance des explications intégrées dans les vidéos pédagogiques mathématiques créées par 37 enseignants stagiaires (femmes = 26, hommes = 11). L'échelle d'évaluation de la vidéo pédagogique (IVES), composée de quatre concepts (établissement du contexte, heuristique d'explication, minimisation de la charge cognitive, engagement), a été utilisée pour évaluer la qualité de deux vidéos (pré-feedback et post-feedback). La vidéo initiale créée par les enseignants stagiaires (pré-rétroaction) a révélé un certain nombre de domaines problématiques, notamment fournir une étiquette claire du problème, utiliser des supports visuels, noter les erreurs potentielles qui pourraient survenir, écrire lisiblement, mettre en évidence les domaines clés, énumérer les termes et formules clés , utilisant une voix claire et conversationnelle et concis Après avoir reçu des commentaires détaillés, basés sur l'IVES, les notes de la deuxième vidéo (post-feedback) pour chacun des problèmes initiaux ont augmenté de manière significative. L'échelle IVES, fondée sur le cadre de Kay (2014), a permis d'identifier et d'améliorer l'efficacité des explications des enseignants de formation sur les concepts mathématiques.

Mots-clés: enseignants stagiaires, vidéos pédagogiques, enseignement des mathématiques, explication

Introduction

Instructional explanations are developed to help learners understand or apply concepts related to a specific subject area (Leinhardt, 2001). Exemplification, or providing examples, is critical for effective mathematics explanations (Bills et al., 2006; Inoue, 2009) and helps simplify abstract mathematical concepts (Rowland, 2008). Kirschner et al. (2006) provide substantial evidence that direct instruction through the use of well-explained worked examples is particularly useful when students have a limited understanding of concepts to be learned. Learning to provide clear and explicit explanations of specific mathematical examples, then, is an essential skill to develop for secondary school pre-service teachers (Atkinson et al., 2000). Developing those explanation skills, especially within pre-service mathematics teacher education, is a complex process (Kay, 2014). A teacher's pedagogical decisions are multifaceted and might involve highlighting mathematical elements, procedures used, choice of technology, and type of representations. Each one of these decisions strongly influences student learning (Kay, 2014).

Educational research on creating effective instructional explanations in mathematics and other subject areas has been side-stepped for many years due to heavy emphasis on problem-based and exploratory methods (Schopf et al., 2019). Consequently, comprehensive, evidence-based frameworks on developing explanatory competency are limited (Kay, 2014; Schopf et al., 2019). However, a set of general guidelines has emerged including referencing previous knowledge, providing clear objectives and structures, demonstrating use of knowledge, presenting examples and general rules, offering visual aids, using straightforward language, following an appropriate pace, and creating a positive atmosphere of humour and enthusiasm (Schopf et al., 2019; Wittwer & Renkl, 2008).

An amalgam of heuristics for creating effective mathematics explanations includes providing an overview at the beginning, following a series of steps in logical order, offering clear definitions, incorporating adequate visualizations, and using appropriate language to match the learner (Schopf et al., 2019). However, a coherent framework for designing and delivering effective mathematical explanations through technology has yet to be developed. Furthermore, data collection on the quality of mathematics explanations is predominantly passive and does not adequately assess the process of explaining.

Literature Review

An alternative approach to examining and fostering high-quality mathematical explanations is to investigate how technology can be leveraged with video-based worked examples. With over 1.3 billion users and 5 billion videos watched each day on YouTube (MerchDope, 2020), an argument could be made that video explanations are becoming more relevant and dominant than face-to-face explanations. The use of videos to explain worked examples has been examined by researchers under different labels, including podcasts (e.g., Crippen & Earl, 2004; Kay, 2014; Loomes et al., 2002), flipped learning (e.g., Long et al., 2016; Sahin et al., 2015; Triantafyllou & Timcenko, 2015), and video lectures (e.g., Giannakos et al., 2015; Ljubojevic et al., 2014). A video format is useful for critically investigating the quality of explanations because it allows both students and instructors to carefully review, replay, compare, and reflect upon critical elements presented.

Consistent with previous research heuristics on explanatory competence (Schopf et al., 2019; Wittwer & Renkl, 2008), Kay (2014) developed an evidence-based framework to guide the creation of effective video-based explanations of worked examples. This framework includes four areas: establishing the context of the problem, explanation heuristics, minimizing cognitive load, and engaging students. *Establishing context* includes providing a clear problem label (Bransford et al., 2000), explaining what the problem is asking (Willingham, 2009), and identifying the type of problem presented (Ball & Bass, 2000). *Providing effective explanations* involves breaking a problem into meaningful steps (e.g., Mason et al., 2010; Polya, 2004), explaining the reasoning for each step, and using visual supports (Atikinson et al., 2000; Clark & Mayer, 2008; Renkl, 2005). *Minimizing cognitive load* encompasses factors such as presenting problems in a well-organized layout, writing clearly, and drawing students' attention to key aspects of the problem using visual highlighting (Clark & Mayer, 2008; Willingham, 2009). Finally, *engaging students* while explaining worked examples refers to using a clear, personalized voice and proceeding at a pace that is suitable for learning (not too fast, not too slow), and minimizing distractions (Atkinson et al., 2005; Clark & Mayer, 2008; Kester et al., 2006).

This study explored the evolution of pre-service teachers' video-based explanations of Grade 7 and 8 mathematical concepts using feedback provided by Kay's (2014) instructional framework.

Research Design and Methods

Participants

Thirty-seven pre-service teachers (female = 26, male = 11) participated in this study. They were enrolled in a 12-week course focusing on teaching mathematics taught in Grades 7 to 12 (intermediate/senior level). This course was part of a 1-year Bachelor of Education program, situated in a small university (8,000 students) within a community of 650,000 people. English was the second language for 32% (*n* = 12) of the participants.

Data Collection

The Instructional Video Evaluation Scale (IVES), based on Kay's (2014) framework, was used to analyze the video-based mathematical explanations of the pre-service students.

The IVES, consisting of 19 items, focuses on four constructs: establishing context (n = 3 items), creating effective explanations (n = 7 items), minimizing cognitive load (n = 4 items), and engagement (n = 5 items). Each item in the IVES was rated on a three-point scale (0 = No, 1 = Sort of, 2 = Yes) assessing whether a pre-service teacher demonstrated a specific explanation quality.

The first construct, establishing context (problem label, type, key elements), had an internal reliability coefficient of 0.77. The second construct, creating effective explanations (all key steps, clear reasoning, mathematical conventions, appropriate strategy, tips, visuals, potential errors), had an internal reliability coefficient of 0.85. The third construct, minimizing cognitive load (organized layout, readability, highlighting, support information), had an internal reliability coefficient of 0.60. The final construct, engagement (limiting distractions, pace, voice, length, tone), had an internal reliability coefficient of 0.69. With the exception of the cognitive load construct, the internal reliability values are considered acceptable for scales used in social sciences (Kline, 1999; Nunnally, 1978).

Procedure

During a 2-hour teaching session, we introduced pre-service teachers to screencasting software (Camtasia) and how to use the required hardware (laptop computer with a Wacom tablet). At the end of the teaching session, we asked them to create instructional videos covering one or more mathematics concepts in the Grade 7 or 8 Ontario Elementary Mathematics Curriculum (Ontario Ministry of Education, 2005). We then provided pre-service teachers with a detailed description of the criteria for each of the 19 items in the IVES to help guide the creation of their instructional mathematics videos.

Each student created one 4- to 6-minute instructional video on a self-selected topic within the Grade 7 or 8 Ontario Mathematics Curriculum (Ontario Ministry of Education, 2005). These videos addressed four of the five strands in the Ontario Mathematics Curriculum: (i) numbers and number sense (n = 10 videos), (ii) geometry and spatial sense (n = 13 videos), (iii) patterning and algebra (n = 6 videos), and (iv) data management and probability (n = 8 videos).

After students created the first video (pre-feedback), they received detailed feedback based on the IVES framework. We then asked the students to create a second 4- to 6-minute instructional video (post-feedback) on the same topic as the first.

Data Analysis

For the first video (pre-feedback), we calculated means and standard deviations for each item on the IVES to provide an overview of pre-service teachers' initial explanation skills. Next, we compared the percentage of pre-service teachers who fully achieved items on the IVES to identify where students excelled and struggled with mathematical explanations. Finally, we conducted paired t-tests for the entire IVES scale (total score), individual IVES items, and the length of videos to determine whether the quality of mathematics explanations changed based on feedback provided by the IVES.

Research Questions

We addressed two research questions in this study:

1. What strengths and challenges do pre-service teachers demonstrate when creating instructional video explanations of Grade 7 and 8 mathematics content?
2. How does the quality of mathematical explanations provided by pre-service teachers change based on feedback from the IVES?

Results

Overview

A paired *t*-test revealed that the average IVES post-feedback score (*M* = 1.51, *SD* = 0.48) was significantly higher than the average IVES pre-feedback score (*M* = 1.37, *SD* = 0.45) $t(36) = 2.54$, $p < .05$ with a medium effect size of 0.29 (Cohen, 1988, 1992). In other words, the overall quality of explanations increased significantly after pre-service teachers received feedback based on the IVES framework. A second paired *t*-test indicated that the average post-feedback mathematics instructional video (*M* = 234.0 seconds, *SD* = 73.7) was significantly longer than the average pre-feedback video (*M* = 352.5 seconds, *SD* = 147.4), with a large effect size of 1.02 (Cohen, 1988, 1992).

Establishing Context

The average initial (pre-feedback) *context* item score was 1.53 (*SD*=0.56), the highest of the four IVES themes. Seven out of ten students were able to articulate the context and type of problem addressed in the video, and six out of ten were successful at noting the key elements for solving the problem, but only half of the students fully achieved the criteria of correctly labelling the problem (Table 1).

A paired *t*-test comparing average pre- and post-feedback total context scores was not significant ($t(36) = 0.09$, *ns*). Paired *t*-tests conducted on the three individual context items on the IVES revealed no significant differences between pre-feedback and post-feedback scores.

Table 1

Pre- vs. Post-Feedback Video Scores for Establishing Context Items (n = 37)

Item	Pre-Feedback Mean (SD)	Item Fully Achieved	Post-Feedback Mean (SD)	Item Fully Achieved
Context and type of problem articulated	1.59 (0.64)	68%	1.57 (0.65)	65%
Key elements of problem explained	1.54 (0.61)	60%	1.54 (0.69)	65%
Clear problem label	1.46 (0.65)	54%	1.51 (0.73)	65%
Total context score	1.53 (0.56)	NA	1.54 (0.62)	NA

Creating Effective Explanations

The average initial (pre-feedback) *explanation* item score was 1.27 (*SD* = 0.52), the lowest among the four IVES constructs. Approximately six out of ten students were successful at showing and explaining all the key steps in their mathematics problems and using the correct mathematical conventions. About half the students were able to offer a suitable strategy or tip for solving problems. Only one quarter of the students offered visuals to support their explanations or noted potential errors one might make when solving the problem addressed in the

video (Table 2).

The average post-feedback total explanation score was significantly higher than the average pre-feedback score, with a medium effect size (Table 2). Paired t-tests comparing pre- and post-feedback scores for the seven individual explanation items on the IVES indicated significant gains for two items: the use of visuals to support explanations, and communicating potential errors that students could make when trying to solve the mathematics problem (Table 2). The effect size for the use of visual supports item is considered medium, according to Cohen (1988, 1992). The effect size for the noting potential errors item is considered small, according to Cohen (1988, 1992). It is worth noting that these two items were the lowest-rated explanation items on pre-feedback videos. The remaining five explanation construct items showed no significant increases between pre- and post-feedback scores.

Table 2

Pre- vs. Post-Feedback Video Scores for Effective Explanation Items (n = 37)

Item	Pre-Feedback Mean (SD)	Item Fully Achieved	Post- Feedback Mean (SD)	Item Fully Achieved
Show all key steps	1.59 (0.60)	65%	1.65 (0.59)	70%
Explain reasoning behind each step	1.49 (0.65)	57%	1.62 (0.64)	70%
Use correct mathematics conventions	1.46 (0.69)	57%	1.54 (0.61)	60%
Use appropriate strategy to solve problem	1.41 (0.64)	49%	1.54 (0.65)	62%
Offer tips for solving problems	1.35 (0.75)	51%	1.46 (0.80)	65%
Use visuals to support explanation	0.89 (0.74)	22%	1.27 (0.87) [1]	54%
Note potential errors that could be made	0.70 (0.88)	27%	0.92 (0.92) [2]	38%
Total effective explanation score	1.27 (0.52)	NA	1.43 (0.56) [3]	NA

[1] – t (36) = 2.90, p <. 01

[2] – t (36) = 2.10, p <. 05

[3] – t (36) = 2.37, p <. 05

Minimizing Cognitive Load

The average cognitive load item score was 1.43 (*SD*=0.42), the second highest among the four IVES themes. Eight out of ten students provided a clear, organized layout for presenting their problems. Half the students had legible writing and visually highlighted key points in the video explanations. Only one third of the students listed key supportive elements like key terms or formulas needed to solve the problems (Table 3).

The average post-feedback total cognitive load score was significantly higher than the average pre-feedback score, with a medium effect size (Table 3). Paired *t*-tests comparing pre- and post-feedback scores for the four cognitive load items on the IVES revealed a significant increase in listing key supportive elements when providing a mathematical explanation (Table 3). The effect size for this increase is considered medium, according to Cohen (1988, 1992). It is worth noting that listing key supportive elements was the lowest-rated cognitive load item in the pre-feedback videos (Table 3). The remaining three cognitive load items increased, but not significantly (Table 3).

Table 3

Pre- vs. Post-Feedback Video Scores for Cognitive Load Items (n=37)

Item	Pre-Feedback Mean (SD)	Item Fully Achieved	Post- Feedback Mean (SD)	Item Fully Achieved
Clear, organized layout of problem	1.78 (0.48)	81%	1.81 (0.46)	84%
Readability of writing	1.43 (0.60)	49%	1.54 (0.69)	65%
Visually highlighting key points	1.41 (0.69)	51%	1.46 (0.77)	62%
Listing supportive elements	1.11 (0.74)	32%	1.46 (0.73)[1]	59%

Total cognitive load	1.43 (0.43)	NA	1.57 (0.52)[2]	NA

[1] – t (36) = 2.10, $p < .05$

[2] – t (36) = 2.22, $p < .05$

Engagement

The average engagement item score was 1.37 (*SD* = 0.52), the third highest among the four IVES themes. Six out of ten students limited distracting behaviour (e.g., saying "uhm" too often, clearing throat, poor sound quality) and proceeded at a pace that was effective for learning a new concept. Half the students were successful at using a clear, engaging conversational voice to present concepts and provide an explanation that was not too long or too short.

The average post-feedback engagement score was significantly higher than the average pre-feedback score, with a medium effect size (Table 4). All five individual engagement items increased from pre- to post-feedback scores. However, paired *t*-tests conducted on the five individual engagement items on the IVES revealed that these gains were not significant (Table 4).

Table 4

Pre- vs. Post-Feedback Video Scores for Engagement Items (n=37)

Item	Pre-Feedback Mean (SD)	Item Fully Achieved	Post- Feedback Mean (SD)	Item Fully Achieved
Limiting distractions	1.46 (0.80)	65%	1.73 (0.60)	76%
Effective pace for learning	1.43 (0.80)	62%	1.57 (0.60)	62%
Clear voice	1.41 (0.73)	54%	1.57 (0.69)	58%

Appropriate length of explanation	1.32 (0.78)	51%	1.46 (0.80)	65%
Engaging conversational voice	1.24 (0.80)	46%	1.46 (0.69)	46%
Total engagement score	1.37 (0.52)	NA	1.56 (0.52)[1]	NA

[1] – t (36) = 2.68, p <. 05

Discussion

Providing effective explanations is an essential skill for mathematics teachers (Bills et al., 2006). In support of developing this skill, we assessed changes in video-based explanations created by pre-service secondary teachers using four constructs: establishing context, creating effective explanations, minimizing cognitive load, and engagement.

Establishing Context

Regarding establishing context in their initial (pre-feedback) video explanations, most pre-service teachers were able to communicate the type of problem presented. However, 40% struggled with presenting the key elements required to solve the problem. Pre-service teachers are just beginning to unpack their previously automatized mathematical knowledge to make it useful for teaching (Ball & Forzani, 2009). The more automatized their knowledge, the harder it is to unpack and communicate the required steps to explain the mathematics concepts. Pre-service teachers might need more direct guidance with elementary mathematics problems, or they may need to observe students trying to solve these problems to better understand which elements are essential for naïve or new learners (Santagata & Bray, 2016).

Almost half of the pre-service teachers were unable to provide a clear label for their problem, an issue that may be related to new teachers not having an evolved schema of how to organize and categorize problems. Without entirely unpacking their knowledge, beginning teachers can solve mathematics problems, but may not understand the big picture well enough to provide adequate labels or descriptions. Further research, perhaps in the form of interviews, could be used to understand the challenges that pre-service teachers have with establishing context.

Effective Explanations

Half of the pre-service teachers had difficulty selecting an appropriate strategy and offering tips to solve a problem in their first video (pre-feedback). This finding highlights the need for teacher education programs to spend more time explicitly focusing on the connections between problem solving and making thinking explicit. After making these connections, pre-service teachers can use that knowledge to provide more effective explanations for their students. Pre-service teachers need to be cognizant of the difference between solving and explaining problems.

Additionally, only 20% of pre-service teachers used visual aids to support their video-based mathematical explanations. This result signifies a need for teacher education programs to focus on how representations and visual aids might improve the quality of explanations (Arcavi, 2003). After receiving direct feedback from the IVES, though, pre-service teachers' scores on providing visual aids increased significantly for the second video (post-feedback). Directing attention to the value of visual aids can lead to short-term changes.

Finally, only one third of pre-service teachers were able to note potential errors in the pre-feedback videos. This finding is in line with other research showing that pre-service and novice teachers require explicit instruction in noticing (Mason, 2002) and anticipating student misconceptions and errors (e.g., Lee & Francis, 2018; Son, 2013). Again, the advanced mathematical knowledge that pre-service teachers have, especially when solving relatively straightforward Grade 7 and 8 problems, undermines their ability to identify potential errors because they do not make these errors and therefore have difficulty anticipating them. Consequently, this research highlighted the continued necessity of including mathematical error analysis to create effective explanations in teacher education programs. Drawing attention to this weakness resulted in significant improvements on this item in the second video (post-feedback)

Cognitive Load

For cognitive load, most pre-service teachers presented problems in a clear, organized format. Half the pre-service teachers had legible writing and highlighted key points; however, feedback based on the IVES scale did not significantly improve these qualities. Future research endeavours could focus on why these two features are resistant to change.

Writing down supportive elements such as the definition of terms or formulas proved to be challenging for the pre-service teachers. Similar to establishing context, writing down supportive elements is connected to pre-service teachers' unpacking of their automized mathematical knowledge. Our finding aligns with recent calls by Krupa et al. (2017) for more research regarding mediating secondary teachers in noticing student thinking. Pre-service teachers could improve their explanations by identifying, highlighting, and writing down key elements to support student thinking. Making students aware of this problem through feedback from the IVES resulted in significant increases in pre-service students listing supportive elements.

Engagement

Overall, pre-service students scored highest on creating engaging mathematical explanations for their first videos (pre-feedback). Many pre-service teachers limited distracting behaviours and explained the mathematical examples at a pace that was neither too fast nor too slow. Using a clear and engaging conversational tone was a little more challenging for the students. Voice may be more critical in a video than a face-to-face explanation but using a more personalized tone is likely more effective, regardless of the environment (Kay, 2014). Changing voice may be one of the more challenging skills to develop with pre-service teachers. Finally, about half the students struggled with creating a video that was long enough to provide sufficient detail. The automatization of knowledge might make pre-service teachers somewhat blind to the level of detail required for a novice learner (Ball & Forzani, 2009). However, feedback from the IVES led students to create significantly longer post-feedback videos. It is also worthwhile noting that although no individual item in the engagement construct improved significantly as a result of receiving feedback from the IVES, the overall average construct score did increase significantly. Again, pre-service students appeared to be responsive to direct, explicit feedback on their explanation skills.

Conclusions

Overall, the IVES appeared to be a useful metric for analyzing instructional mathematics videos created by pre-service teachers and identifying potential opportunities for improvement in explanatory competence. Feedback based on the IVES was significantly helpful in improving particularly weak problem areas such as providing visual supports (representations), noting potential errors that students could make, and listing supportive elements. However, the majority of the 19 items assessed by the IVES did not show a significant improvement after pre-service teachers received feedback. Developing high-quality explanation skills takes time because pre-service teachers have to unpack their automized mathematical knowledge (Ball & Forzani, 2009), observe and understand naïve learners (Santagata & Bray, 2016), and notice student misconceptions and thinking (Krupa et al., 2017; Lee & Francis, 2018; Son, 2013).

This study is a first step in systematically exploring the use of videos to improve the quality of pre-service teachers' mathematical explanations. However, the sample was small, and the period for examining improvements in these explanations was relatively short. Future research might explore the progression of pre-service teachers' explanation skills over an entire semester, year, or program to identify the rate at which specific skills develop. In addition, interviews would help identify the source and progression of acquiring specific explanation skills identified by the IVES. Finally, student ratings of explanations would help validate the criteria noted in the IVES and possibly add new essential elements to aid the development of mathematics explanation skills.

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