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An Observation Protocol Measuring Secondary Teachers' Implementation of Dynamic Geometry Approach*

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Abstract

Studies that measure the impact of an instructional intervention rely on measures of fidelity in the classroom, especially when the intervention involves the use of technology. To examine the extent to which teachers implement a dynamic approach to teaching geometry in secondary classrooms, we develop a 25-item observation protocol based on four dimensions which include planned and implemented dynamic geometry approach elements, quality of instruction, and engagement and discourse. We present evidence of reliability and validity of the instrument.

Keywords: Secondary; Dynamic geometry; Observation protocol; Teaching practices.

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1. Introduction

Since the publication of the U. S. Common Core State Standard for Mathematics (CCSSM), the nature of the teaching and learning of geometry in secondary schools has changed to explicitly include transformational geometry and the use of dynamic geometry environments to "provide students with experimental and modeling tools that allow them to investigate geometric phenomena in much the same way as computer algebra systems allow them to experiment with algebraic phenomena" (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010).

Research suggests that alternatives to traditional instructional approaches can be successful in moving students toward meaningful justification of ideas. "In these approaches, students worked cooperatively, making conjectures, resolving conflicts by presenting arguments and evidence, proving nonobvious statements, and formulating hypotheses to prove. Teachers attempted to involve students in the crucial elements of mathematical discovery and discourse" (Battista & Clements, 1995, p.50).

Dynamic geometry (DG) is an active, exploratory study of geometry carried out with the aid of interactive computer software such as the Geometers' Sketchpad (GSP) (Jackiw, 2001). The instructional approach for using DG software to facilitate students' learning is referred to as the DG approach in this paper. Many researchers have conducted studies on using the DG approach in geometry learning. In a study conducted by Hannafin, Burruss, & Little (2001), findings centered around two main themes: issues of power and learning. While the teacher had difficulty relinquishing control of the learning environment, students liked their new freedom encouraged by the DG instruction, worked hard, and expressed greater interest in the subject material. Vincent (2005) found that the dynamic visualization offered by the DG software motivated and fostered conjecturing and intense argumentation; and that the teacher's intervention–prompting the students to furnish valid justifications for their statements–was an important feature of the students' argumentations. Hollebrands (2007) identified different purposes for which students used dragging and measuring when exploring in DG environments. These purposes appeared to be influenced by students' mathematical understandings that were reflected in how they conducted reasoning about physical representations, the types of abstractions (empirical abstractions, pseudo-empirical abstractions, or reflective abstractions) they made, and the reactive or proactive strategies they employed. Baccaglini-Frank and Mariotti (2010) presented "a model describing some cognitive processes that can occur during the production of conjectures in dynamic geometry and that seem to be related to the use of specific dragging modalities" (p. 225) and used it to analyze students' explorations of open problems. Thus, *w*hen used as a cognitive tool, DG technology can facilitate students'

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exploration and investigation activities, promote their conjecturing, verifying, explaining, and logical reasoning abilities, and enhance their conceptual understanding of important geometric ideas.

A research project funded by the National Science Foundation (NSF) conducted repeated randomized control trials to investigate the efficacy of an approach to high school geometry that utilizes DG software to engage students in constructing mathematical ideas through experimentation, observation, data recording, conjecturing, conjecture testing, and proving. This approach was referred to as the DG approach in the project, and the DG software used by the project was GSP.

This paper describes an instrument developed by the DG project research team to measure the fidelity of DG implementation. The paper proceeds as follows. Section 2 presents background studies related to measuring teaching practices using observation protocols. Section 3 describes the development of the instrument, evidence of reliability and validity, while Section 4 concludes with a discussion.

2. Background

Many education researchers have observed school classrooms and measured their characteristics for different purposes (Shavelson, Webb and Burstein, 1986). The number of classroom observation instruments reviewed by Roshenshine and Furst (1973) and later Brophy and Good (1986) is almost as large as the number of studies reviewed – over 150. These particular instruments measured only behaviors related to teaching in general, such as pacing of instruction, classroom management, clarity and questioning the learners. More recently, observation protocols have been developed in the context of measuring teacher and teaching quality such as the Framework for Teaching (Danielson Group, 2011), the Local Systemic Change (LSC) Classroom Observation Protocol (Horizon Research, 2005) and the Classroom Assessment Scoring System (CLASS) (Pianta, La Paro, & Hamre, 2007). Although these protocols are commonly used, even in international settings, they are not designed to measure the teaching quality of a specific content domain. In response to the need to better explain the mathematical aspects as well as the mathematical pedagogy harnessed during lessons, mathematics educators have turned their attention to the development of more specific observation protocols and instruments. Two observation protocols with published validity information aligned with content specific teaching and practices are 1) the Reform Teaching Observation Protocol (RTOP) for mathematics and science (Sawada et al., 2002; Piburn et al., 2000) and 2) Mathematical Quality of Instruction (MQI) for mathematics (Hill, Charalambos, & Kraft, 2012; Hill et al., 2008; Learning Mathematics for Teaching Project, 2011). For the purpose of measuring a specific area within mathematics, Geometry, and a specific approach inherent by the content itself, the dynamic approach, we found the above protocols informative but not adequate. Next, we describe how we adapted the RTOP and

MQI elements to design a unique observation protocol to measure the extent to which the dynamic geometry approach is implemented in secondary geometry classrooms.

3. Measuring implementation of Dynamic Geometry approach with an observation protocol

3.1. Instrument Development

The purpose of the observation protocol in the Dynamic Geometry (DG) Project was to measure the *fidelity of implementation*, or the extent to which teachers implemented the DG approach in their classrooms. We began with the development of a blueprint for dynamic geometry teaching based on a review of empirical studies and key documents related to the teaching and learning of geometry with technological tools (e.g., Hollebrands, 2007; Baccaglini-Frank and Mariotti, 2010; NCTM, 2000), mathematics quality of instruction (Hill, et al. 2008, Stein, et al. 2000), and reformed teaching (Pibum & Sawada, 2002). Table 1 shows the four dimensions of the blueprint serving as the basis for the observation protocol. Our team developed most of the items, but some were adjusted from existing items developed by previous researchers. Each item used a 4-point Likert response scale borrowed from the *Reformed Teaching Observation Protocol* (RTOP) from never occurred (0) to very descriptive (4). The scale reflects the degree, to which the aspect was *characteristic* of the lesson observed, as opposed to the number of times the aspect occurred.

Using an initial protocol of 34 items, the research team observed and scored a set of videotaped lessons taught by geometry teachers. In addition, external experts were consulted for feedback on the items. The purpose of this process was to improve the description of the items and to write a training manual that could help raters achieve the desired level of reliability. The training consisted of detailed explanations of each aspect, use of a video lesson taught by a master teacher (a high school teacher with rich experience in geometry curriculum and instruction working for the DG project) to practice coding, discussion of disagreements, and clarification of terms. For a multi-year project exploring the effect of the DG approach on students' geometry learning, an instrument that could describe the fidelity of the DG implementation was necessary. During the first year of DG implementation, pairs of trained raters completed observations of the same class and met immediately afterwards to discuss codes. Both independent codes and reconciled codes were collected for analysis. In spring 2011 a total of 66 observations were processed (33 geometry lessons). The inter-rater reliability for this initial set of observations was 0.837. The external experts continued to improve the instrument after its first-year use in the classrooms. For example, the initial instrument had the simple descriptor "the lesson leads the class to drag", that was improved to a fuller description: "the lesson leads the class to drag for the purpose of determining whether observed quantities and/or relationships remain constant, are changing, or are otherwise impacted by the action." The final version of the DG Observation Protocol (DGOP) consists of 25 items organized in the same four dimensions described in Table 1(see entire instrument in Appendix A).

Table 1

Dimensions of Dynamic Geometry Teaching Approach

Dimension 1: Intended Dynamic Geometry Approach
The lesson as planned has key features of the DG approach (e.g. tasks that involve the use of the dynamic moving and measuring functions of the software to do observations and explorations; activities move students from initial conjecture, to investigation, to more thoughtful conjecture and, to verification).
Dimension 2: Implemented Dynamic Geometry Approach
The lesson as implemented has key features of the DG approach. This includes the use of software functions (drag, transform, animate, measure, and construct) and actions beyond the use of software (observation, investigation of mathematical relationships in multiple ways, form and test conjectures, motivated to think mathematically, and prove their conjectures).
Dimension 3: Quality of Instruction (Teacher's Role)
Teacher provides opportunities for students to engage in high levels of cognitive demand mathematical practices, teacher demonstrates knowledge for teaching geometry in the dynamic technological environment, and teacher guides the student through the process of conjecturing and proof process.
Dimension 4: Engagement and Discourse
Students share questions, hints, and progress reports with their neighbors. Students offer and request help from their peers when working on their own computer. Students engage in whole-class discussion when necessary.

3.2. *Evidence of Reliability*

During the second year of DG implementation, the final observation protocol was used in 25 geometry lessons. As before, two members of the research team observed and independently coded each lesson. The estimates of inter-rater reliability were calculated by a regression line of the observation of one observer on those of the other. Figure 1 shows the scatter plot of the data points with a correlation coefficient of 0.901 and the proportion of variance explained (*R*-Squared) by the line is 0.812. These estimates of reliability are high and comparable with the RTOP instrument, which has a correlation coefficient of 0.98 and an *R*-Square of 0.954 (Sawada et al., 2002).

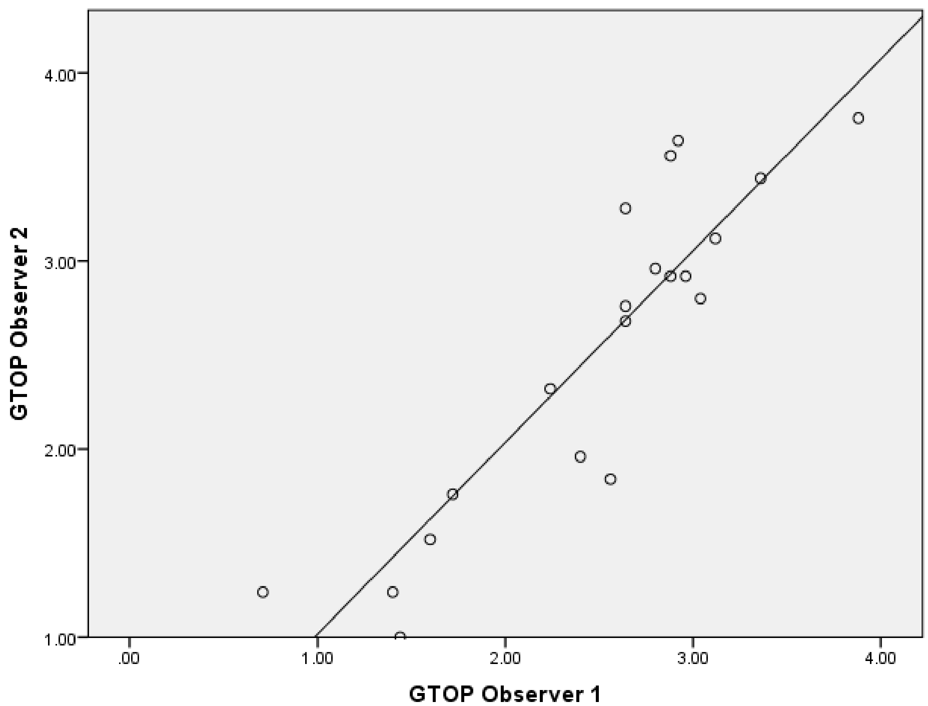

*Figure 1***.** Estimate of inter-rater reliability of the observation protocol from observations in geometry classes. (*R* – Square = 0.812)

Further evidence of reliability of the observation protocol is presented in Table 2 where estimates were computed for each dimension or subscale and the instrument as a whole. Note that all the dimensions, except for the Intended DG Approach, have high estimates of reliability. Two things can be attributed to these lower estimates in this particular dimension. One possible explanation is the fact that the dimension was measured with only five items and the second possible explanation is that the items heavily depend on lesson plans and instructional materials available to the observers at the time of the observation. When these materials were not available, the observers were instructed to infer the intended goals and design of the lesson from the observed implemented lesson.

Table 2

Reliability Estimates for Dimensions of observation protocol

Dimensions	Correlation	*R* - Squared
Intended DG Approach	0.681	0.464
Implemented DG Approach	0.911	0.830
Quality of Teaching	0.815	0.664
Engagement	0.825	0.681
Overall observation protocol	0.901	0.812

3.3. Evidence of Face Validity

The face validity of the observation protocol draws on three major sources: (a) *Common Core State Standard for Mathematics*, and *Principles and Standards for School Mathematics* (NCTM, 2000); (b) *Reform Teaching Observation Protocol* (RTOP) for mathematics and science (Sawada et al., 2002; Piburn et al., 2000), and *Mathematical Quality of Instruction* (MQI) for mathematics (Hill, Charalambos, & Kraft, 2012; Hill et al., 2008; Learning Mathematics for Teaching Project, 2011); and (c) the operational definition of the dynamic geometry approach (Jiang et al., 2011). The detailed relationship between these documents and the observation protocol can be found in the reference manual and technical reports in Appendix B.

3.4. Evidence of Construct Validity

To test the hypothesis that *inquiry-oriented conjecturing and proving* is a powerful integrating force in the structure of the observation protocol, a correlational analysis was performed on the four dimensions or subscales. Each subscale will be used to predict the total score. High *R*-Squared values would support the hypothesis, offering strong support for the inquiry-base conjecturing and proving construct validity of the observation protocol (Table 3).

Table 3

Domains as Predictors of the Observation Protocol Total Score

Domains	Correlation	*R* – Squared
Intended DG Approach	0.842	0.709
Implemented DG Approach	0.970	0.941
Quality of Teaching	0.897	0.805

Engagement	0.611	0.373

Except for the last domain of Engagement, all the domains are high predictors of the total observation protocol scores, providing strong evidence of the inquiry-oriented conjecture and proving validity of the observation protocol. The domain of Engagement relates to student and teachers practices around participation, discourse, and remediation. These practices, although important elements of the DG approach, are the most independent of the other domains in the sense that a lesson could score high on this dimension but low in the others or vice-versa. For example, teachers and students could be actively engaged in the class by discussing and helping each other about a topic that did not involve any of the intended or implemented goals of the lesson. In an inter-domain correlation analysis (not shown here) the only low correlation was between Engagement and Implemented DG Approach, providing evidence that these two domains are not highly associated.

To better understand construct validity of observation protocol we examined a two case studies of teachers, using their observation protocol scores, notes from observers that accompanied the observation protocol instrument, as well as the two teachers' own self-reports provided approximately monthly during each school year. The self-reports asked teachers to describe how they used DG to explore, conjecture, and prove in their classrooms, how/if they felt students were learning, and a variety of other questions aimed at issues of fidelity.

Maria scored very high on her observation protocol; outscoring all other DG teachers nearly every time. These scores should indicate that she is faithful to the DG approach. Her self-reports corroborated this information and added some nuance. Throughout the first year of the project she reported being very excited about using DG and thought the approach was helping her students learn. She described many lessons she had conducted or planned to conduct and these seemed in line with the observed lessons in terms of DG usage. As the first year drew to a close her self-reports indicated frustration with her curriculum calendar and how it conflicted with her desired use of DG for her students. For example, she preferred using two days per DG lesson where the first day was exploring and conjecturing and the second day wrapped up conjecturing and proving. She indicated that she felt pressured by the pace of her district's calendar to use DG less often and that by the end of the year she had been using DG more as a demonstration on the overhead projector than as an exploration activity with students at shared computer stations. The observations during the first year did not capture demonstration usage, we suspect, because many of her self-reports indicating this change happened after the conclusion of observations in her class for that year.

The second year our observations again ranked her highly in terms of observation protocol scores. Her self-reports again shifted away from beginning-year enthusiasm to more hesitancy to use the DG approach as often as she had in Year 1 and with a shift, again, to teacher-led demonstrations. Again, we do not have observer data that matches a demonstration approach to DG, as she described in her self-reports. We suspect this may be for two related reasons. Firstly, she never stated that she'd given up student-led DG lessons, just that she shifted away from using them as frequently. Secondly, it is likely that she planned her student-led lessons on days we observed. Our observations and her self-reports indicate that she can and did lead careful DG lessons with her students. The observation protocol captured these well. But the limited time to observe in her classroom did not allow for observation protocols to capture her changing approach to her lessons. The observation protocol seemed to be an indicator of her ability to lead a great lesson more so than a measure that she sustained this throughout the project. The observation protocol, then, seemed to measure her propensity and ability to do DG well rather than a measure that most or all of her lessons were of this high quality. We hypothesize that many of her later-year lessons, if we were able to observe more frequently, would reveal that her observation protocol scores would decrease in as much as she began using DG less often with students' leading the explorations, conjecturing, and proving. We further hypothesize that the observation protocol would still capture that distinction.

Carla, by contrast, scored low to medium on her observation protocol in Year 1 of the project (far below Maria). Her self-reports that year also corroborated those scores. She frequently mentioned ordering DG lessons differently than the project envisioned, going so far as to acknowledge fully in her reports that she was using the technology in "reverse" order. She taught concepts first in the classroom and then had students use GSP in the lab to verify results already learned rather than to explore as new content with the technology. Her low observation protocol scores aligned with her self-reported usage; that her lessons were not explorations of ideas but were verifications of already learned material. As the first year drew to a close her self-reports indicated that she wanted to try to do more exploring first with DG, but was not yet ready to fully change her teaching style.

Her Year 2 self-reports suggested that she underwent the change she had been considering the previous year. She began to reserve every Monday in the lab for students to explore and conjecture and then spent the rest of the week unpacking the ideas encountered in the Monday DG labs. Subsequent observations in her classroom, after her self-reported change, generated new observation protocol scores that were much higher than her Year 1 scores. This seemed to suggest that the observation protocol captured her range of lessons across both years.

In conclusion these two cases suggest the observation protocol can measure the overall fidelity to DG at least on the days observed. In Carla's case, she began the project not using DG as faithfully as the project envisioned and the observation protocol seemed to accurately measure that usage. The observation protocol was, though, able to measure her changes after Year 1, as she began to be more faithful to the project's intentions for

DG in the classroom. In both years her observation protocol scores matched her reported usage. Maria presents a more difficult case of fidelity. From the start Maria was quite skilled at teaching using the DG approach and her ability to do so did not decrease as her observation protocol scores revealed. What did seem to decrease, evidenced by her self-reports, was her frequency to use this style of DG lesson.

4. Discussion

In the continually-evolving world of technology, the teaching and learning of geometry in US secondary classrooms is becoming more dynamic in nature. By using a dynamic approach to teaching geometry, students are more exposed to more mathematical practices that facilitate the learning of processes such as exploring, conjecturing, and proving (Jiang et al, 2011). As this approach to teaching geometry is more-widely implemented in classrooms, either as part of curricular innovations or as future research projects, appropriately measuring the fidelity of DG implementation is necessary. Despite time and labor intensiveness of classroom observations, a measuring method that relies on observational data is needed to address the drawback of relying solely on teachers' self report when capturing implementation fidelity. This was why the DG Observation Protocol was developed and used in the project.

The DG Observation Protocol (DGOP) was built upon dynamic geometry research literature, measures of quality and reform teaching, and external experts' advice. The operationalization of the DG approach allows observers to measure the extent to which the DG approach is intended and implemented in the classroom. Our data show that with training, teams of observers using DGOP can reach high levels of inter-rater reliability. Further, quantitative and qualitative analyses of our observations provide evidence that the scores stemming from the observation protocol reflect the degree of fidelity of the implementation of the DG approach.

Some scholars may argue that certain aspects of teaching geometry in a dynamic environment are not captured in DGOP. A possible example may be, students' technological moves and discourses as they explore and conjecture during the lesson seem necessary to assess the level of engagement with the approach. However, with established validity and reliability this observation protocol has painted a clear picture of the DG approach that teachers implemented and provides a mechanism to quantifying that specification. It has the great potential_to serve as a tool to further investigate the nature of the teaching and learning of geometry in dynamic environments.

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Appendix A

I. DESCRIPTION OF *INTENDED* DYNAMIC GEOMETRY LESSON

1. The lesson has appropriate objectives for the concept(s) being explored.
2. The lesson includes tasks that involve the use of the dynamic moving and dynamic measurement functions of the software to do observations and explorations.
3. The activities develop the notion of "figure" rather than "drawing" – attending to underlying relationships rather than particular of a specific drawing.
4. The activities in the lesson are designed to move students along the following trajectory (or part of it): from initial conjecture, to investigation, to more thoughtful conjecture, to verification and proof.
5. The activities are designed to so that students observe interesting mathematical phenomena and are motivated and challenged to understand why these phenomena occur and to explain them logically.

II. DESCRIPTION OF *IMPLEMENTED* DYNAMIC GEOMETRY LESSON

The lesson leads the class to

6. construct with limited explicit guidance by the teacher or other materials (i.e. handout w/ specific steps).
7. "drag" for the purpose of determining whether observed quantities and/or relationships remain constant, are changing, or are otherwise impacted by the action,

8. measure for the purpose of further exploring relationships and/or conjecturing, and/or disproving
9. observe the various quantities/qualities of their sketches, particularly relationships that might lead to conjectures or proofs
10. investigate mathematical relationships in multiple ways including using transformations and/or animations,
11. form conjectures based on students' interactions with the software,
12. test conjectures using the software or other means (i.e. deductive reasoning),
13. take advantage of immediate feedback (as offered by the software or teacher)
14. reason inductively and/or deductively throughout
15. prove (or disprove) their conjectures.

III. ASSESSMENT OF *QUALITY* OF TEACHING

LEVEL OF COGNITIVE DEMAND
16. Students engage in recollection of facts, formulae, or definitions. (*Memorization*)
17. Students engage in performing algorithmic type of problems and have no connection to the underlying concept or meaning. (*Procedures without connections*)
18. Students engage on the use of procedures with the purpose of developing deeper levels of understanding concepts or ideas. (*Procedures with connections*)
19. Students engage in complex and nonalgorithmic thinking, students explore and investigate the nature of the concepts and relationships. (*Doing Mathematics*)
TEACHERS' OBSERVED KNOWLEDGE
20. The teacher has a solid grasp of the geometry content at the level he or she is teaching. (*Grade level geometry knowledge*)
21. The teacher has knowledge of the use of instructional techniques specific to teaching geometry along with a deep understanding of the subject to appropriately integrate instruction with the concepts. (*Mathematical Pedagogical knowledge/knowledge for teaching*)
22. The teacher leads students to the appropriate geometric dynamic actions (drag, transform, animate, measure, and construct) according to the goals of the lesson. (*Dynamic Geometrical knowledge for teaching)*

IV. ASSESSMENT OF ENGAGEMENT AND DISCOURSE

23. Students are encouraged to share questions, hints, ideas, and/or progress with other students
24. Teacher circulates, observes (to monitor progress), asks questions, and provides necessary help as students work.
25. Teacher initiates class discussion when necessary.