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Elementary teachers' use of adaptive diagnostic assessment to improve mathematics teaching and learning: A case study

Dalal H. Alfageh [1], Cindy S. York [2*], Angie Hodge-Zickerman [3], Ying Xie [2]

[1] King Saud University, Riyadh, SAUDI ARABIA
[2] Northern Illinois University, Chicago, IL, USA
[3] Northern Arizona University, Flagstaff, AZ, USA
***Corresponding Author:** cindy.york@niu.edu**

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ABSTRACT

This case study examined teachers' perceptions and use of adaptive diagnostic assessment for improving teaching and learning of elementary-level mathematics. The purpose was to understand how the teaching and learning of mathematics occurred in the classroom and changes that transpired due to the implementation of diagnostic assessments. Findings illustrate that diagnostic assessment can be a critical tool for improving pedagogical practice by enhancing mathematics teaching and learning by creating groups of students, planning lesson time, focused pedagogy, giving student feedback, communicating with stakeholders, and improving teacher efficiency. Participants demonstrated satisfaction with the benefits offered by diagnostic assessment for improving mathematics teaching and learning. Participants described challenges that hindered their effective use of diagnostic assessment tools. The findings of this study support a case for the adoption of diagnostic assessments to improve pedagogical practice and promote mathematics learning among elementary-level students.

Keywords: adaptive diagnostic assessment, mathematics, teachers

INTRODUCTION

Elementary students' mathematics performance has declined over the past years in many schools (Cherif et al., 2017). The abstract nature of mathematics can make it challenging to teach and learn (Schleppegrell, 2007). Mathematics learning difficulties can be troublesome for the affected individual, given the possible adverse effects on lifelong learning abilities and career prospects (Navarro et al., 2012). Thus, it is critical to analyze ways that can reduce difficulties encountered by students when learning mathematics. In this sense, technological advancements have given rise to modern forms of assessment, such as adaptive diagnostic assessment, that have been suggested to aid teachers in structuring instruction for the specific learning needs of students (Shim et al., 2017). Adaptive diagnostic learning suggests that every student should receive the proper lesson at an appropriate level of difficulty, with scaffolding tailored to the student's level of mathematics comprehension (Chang, 2015; Shute et al., 2006). The limited literature on the use of diagnostic assessments in mathematics classrooms for elementary teachers illustrates a need for further research. We note this to be surprising after the COVID-19 pandemic. However, we hope this study will be one of many that contribute to the literature regarding how diagnostic testing can inform the teaching of mathematics teachers. In particular, this study explored teachers' perceptions and use of adaptive diagnostic assessment for improving the teaching and learning of mathematics during elementary school years.

Background

Mathematics has been a crucial part of school curricula since the 1890s, and some advancements in mathematics curricula can be attributed to the technological revolution that has taken place over the past four decades (Cheung & Slavin, 2013; Li & Lappan, 2014). Analysis of mathematics education in schools has revealed that teachers can have difficulty facilitating the understanding of critical mathematics concepts among students (Tseng et al., 2013). A shortage of confident and effective teachers has resulted in much attention being focused on preparing mathematics teachers (Blackley & Howell, 2015; Hill et al., 2005; Schuck, 2016). In addition, there appears to be a lack of teacher preparation programs that meet emerging trends, such as the use of technology in teaching (Hsu, 2016). This was especially noticeable in 2020 when the pandemic took the world by storm,

This paper was derived from Alfageh (2021) and Alfageh and York (2021).

leaving teacher education programs with a more significant responsibility in the role of technology in education (National Academies of Sciences, Engineering, and Medicine [NASEM], 2020). With the now rapid adoption of technology in classrooms, teaching methods without the use of technology could be considered outdated, especially with teachers finding technology integration important to successful teaching (Bacak et al., 2023; Camacho & Legare, 2021; Engelbrecht et al., 2020; Wallick, 2022).

One possible solution to the difficulties faced in teaching and learning mathematics involves shifting focus from mere mathematical content to other aspects, such as exploratory problem-solving and activities promoting the engagement of students to foster a sense of success (Amirshokoohi & Wisniewski, 2018). In that sense, the use of adaptive diagnostic assessment appears to be a tool that could transform how mathematics curricula are designed and how teachers present mathematics concepts and monitor students' progress, depending on how the teachers are using it.

Adaptive diagnostic assessments use advanced technology to provide customized assessments of students and track student growth in comprehending mathematics and other subjects (Shim et al., 2017). Teachers and students can access a diagnostic overview that displays each student's progress (Shim et al., 2017). Adaptive diagnostic assessments can also help teachers gauge students' progress to place them in appropriate mathematics classes (Bohlmann & Fletcher, 2008). More importantly, adaptive diagnostic assessments can be used by teachers to boost achievement in mathematics by offering remedial instruction and takeaway assignments for struggling students (Bohlmann & Fletcher, 2008; Ketterlin-Geller & Yovanoff, 2009; Shim et al., 2017).

The approach of adaptive diagnostics is based on the cognitive perspective of learning and knowledge acquisition, where knowing is presupposed as an asymmetric processing of information. A student understands concepts through reasoning coupled with using both cognitive and metacognitive strategies for solving problems and, in turn, transfers new knowledge to other tasks (De Marsico et al., 2013). The literature appears to agree that cognitive assessments are more productive compared to typical approaches to assessments (Roberts & Gierl, 2010; Treagust, 2012). According to Nichols (1994), educational tests designed for cognitive diagnostic purposes differ from traditional approaches because they do not solely rely on logical taxonomies and content specifications to describe their objectives. Moreover, diagnostic assessments measure students' specific knowledge structures and processing skills to provide information about their cognitive strengths and skills (Kane & Bejar, 2014; Leighton & Gierl, 2007). Adaptive diagnostic assessment implies that teachers can help every learner receive the proper lesson at the right difficulty level, with scaffolding tailored to a student's level of comprehension (Chang, 2015; Shute et al., 2006). By integrating assessment and instruction, mathematical interventions offer adaptation based on students' learning and teachers' strategies (Alexander et al., 2007). Thus, a teacher can identify a struggling student and tailor instruction to focus on the foundational concepts the student requires, along with appropriate practice for mastery (Chapelle et al., 2015). The adaptive diagnostic assessment also provides teachers with a dashboard and detailed reports that show each student's progress and comprehension level on curriculum units based on common or specialized standards (Shim et al., 2017). This fine-tuned diagnostic reporting is used to determine the level of current understanding and offers detailed information about how teachers can target and improve students' weak areas while also helping teachers understand how the learning process is progressing and what appropriate measures to use to improve learning (Buyukkarci, 2014; Chapelle et al., 2015; Guzmán & Conejo, 2015).

It has been found that teachers have embraced the use of adaptive diagnostic assessment because they consider it an effective tool that helps them make long-term informed decisions on how to improve their students' performances (Bohlmann & Fletcher, 2008). Technological applications such as adaptive diagnostic assessments can be critical in supporting mathematics teaching and learning (Higgins et al., 2012). Even so, the authors wanted to dig deeper and better understand how mathematics teaching and learning occurred in the classroom and the changes that transpired due to the implementation of diagnostic assessments. Therefore, this study addressed how adaptive diagnostic technologies could be used in the classroom to enhance the teaching and learning of mathematics from the perspective of teachers, thus helping bridge the gap by offering empirical evidence on the use of adaptive diagnostic assessments to enhance teaching and learning of mathematics at the elementary level.

METHODS

Technological advancements have led to improved means of teaching, such as diagnostic assessments to enhance the teaching and learning of mathematics (Ketterlin-Geller & Yovanoff, 2009; Shute et al., 2006). However, mathematics teaching research needs to focus on what occurs after the diagnostic tool has provided results and what teachers do to modify their mathematics teaching and students' mathematics learning. This study employed a qualitative case study approach to examine teachers' perceptions of and use of adaptive diagnostic assessments and how the results of these assessments contributed to a modification of the teaching and learning of mathematics. This qualitative case study explored and examined the perceptions of teachers who had implemented adaptive diagnostic assessments in their mathematics classrooms for at least one year and up to seven years. IRB was sought and approved as exempt.

Research Questions

To better understand both teachers' use and teachers' perceptions of adaptive diagnostic assessment for improving teaching and learning mathematics during elementary school, this study addressed the following research questions:

1. How did teachers use an adaptive diagnostic assessment tool to improve their mathematics teaching?
2. What were teachers' perceptions regarding the use of an adaptive diagnostic assessment in their teaching of mathematics?

Table 1. Participant demographics

Criteria	Participants					
	Landry	**Pat**	**Jamie**	**Sam**	**Michel**	**Stevie**
Age category (years)	31-35	46+	36-40	36-40	46+	31-35
Highest educational degree	Bachelor	Master	Master	Master	Bachelor	Bachelor
Grade currently teaching	5^{th}	5^{th}	4^{th}	3^{rd}	5^{th}	4^{th}-6^{th}
Years of teaching experience	9-12	17+	17+	13-16	17+	1-4
Years of experience teaching mathematics	5-8	17+	21+	13-16	5-8	1-4
Years of experience using technology for teaching mathematics	7-9	10+	7-9	7-9	7-9	4-6
Years using adaptive diagnostic assessment in teaching	7-9	4-6	7-9	4-6	4-6	4-6

Setting & Participants

This collective case study was purposefully conducted at two Midwestern elementary schools within a district that had used adaptive diagnostic assessments in mathematics classrooms for seven years. The district had 16 elementary schools, and the total number of teachers was 467, with an enrollment of about 9,734 students. The study focused only on K-5 elementary teachers because learners who struggle with mathematics in the elementary years face challenges retrieving basic facts (Bryant et al., 2008). E-mails were sent to 29 K-5 mathematics teachers in the two schools within the district requesting their voluntary participation in the study. Participants were required to have more than one year of experience teaching mathematics and at least a year of experience using adaptive diagnostic mathematics assessment. 11 teachers agreed to participate in the current study and completed the demographic survey. However, only six teachers agreed to participate in the interview and/or focus groups. Therefore, those six are considered the main participants. Gender-neutral pseudonyms were used to protect the participants' identities. However, two-thirds of the six participants identified as female and the rest as male. **Table 1** shows participant demographics.

Data Collection

The research questions were informed by multiple data sources: a demographic survey, individual interviews, a focus group, and reflective field notes. A 20-item online survey was created in Qualtrics and shared via email with the participants to collect data regarding participants' experiences and use of adaptive diagnostic assessment in the mathematics classroom. The first section of the survey covered the participants' background information, including their age, gender, years of experience, and the grade level they teach. The second section covered the participants' use of technology in classrooms. The last section covered the participants' use of adaptive diagnostic assessment to enhance the teaching and learning of mathematics. Eleven participants completed the survey. Interviews were conducted online via Zoom due to COVID-19 and lasted 60 to 90 minutes. The interview and focus group protocol consisted of 25 open-ended questions, providing in-depth insight into the participants' use of adaptive diagnostic assessment to enhance the teaching and learning of mathematics. Four participants took part in individual interviews. Two participated in a focus group. (It had been intended that all six would participate in individual interviews and focus groups; however, COVID-19 prevented this due to the participants' schedules and the time they were willing to provide). Researcher reflective field notes were taken during the individual interviews and the focus group interview to better understand participants' actions, behaviors, body language, and interactions (Creswell, 2009). Interviews and the focus group were recorded and transcribed for data analysis. **Appendix A** shows interview questions.

Data Analysis

The first author (researcher) read through the data collected from the interviews, focus groups, and reflection field notes. From that read-through, tentative labels (or codes) were created for chunks of data that summarize the observed patterns in the data (Creswell, 2012; Gay et al., 2012). During the process, analysis alternated between the different data organized through open coding to develop a deeper understanding of the teachers' use and perceptions of adaptive diagnostic assessment to enhance the teaching and learning of mathematics. Transcripts from the focus group and interviews and the descriptive journal reflection notes for themes according to the research questions were analyzed. Quotations from the interviews were used as support for identified themes.

For data coding, quotations from the interviews and focus groups were used to support the identified themes. Each participant's statements were reviewed within the context of the conversation. A determination was made as to whether each statement was linked to one of the seven components of TPACK framework: content knowledge (CK), technology knowledge (TK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPCK) (Mishra & Koehler, 2007) as a starting point to grouping ideas and themes. By doing so, the authors felt the theoretical underpinning of TPACK framework would help understand or delineate how participants were integrating technological, pedagogical, and CK through the assessment (Koehler et al., 2013; Ozudogru & Ozudogru, 2019).

Four themes were identified under research question one about assessment usage (improved pedagogy, effective time usage, grouping students, changes over time, and technology challenges). Each theme is linked to one or more of the seven components of TPACK framework (CK, TK, PK, PCK, TPK, TCK, and TPCK). The presence of an association or link was determined if a participant's statement represented a core knowledge contained in TPACK framework. For example, CK was identified when the participants mentioned how the technology helped them understand what they needed to teach. TK was identified when the participants mentioned the challenges of using the technology to support instruction. PK was identified when the participants mentioned planning a lesson. TCK was identified when the teachers mentioned grouping the students. TPK was identified when the

participants mentioned using technology to change instruction. PCK was identified when the participants mentioned how the technology helped them make appropriate learning decisions. TPCK was identified when the participants mentioned how technology was used to support the teaching and learning of mathematics. For more information, see **Appendix B**.

Member checking was utilized to ensure the trustworthiness of the findings when the first author emailed the interview transcripts to the participants to ensure accuracy and confirm that the information presented represented their experiences.

RESULTS & FINDINGS

The results and findings address two key aspects: how teachers use adaptive diagnostic assessments to improve mathematics teaching and teachers' perceptions regarding the use of adaptive diagnostic assessment in teaching mathematics. Regarding research question 1, how did teachers use an adaptive diagnostic assessment tool to improve their mathematics teaching, four themes emerged and will be discussed next.

Improved Pedagogy

There was common agreement among the participants that adaptive diagnostic assessment helped to improve and deepen their knowledge regarding how to design classroom instruction efficiently. It emerged that the diagnostic tool provided teachers with necessary information about the level of understanding of the different mathematical concepts among the students, allowing them to provide more individualized feedback. The provision of feedback is a critical element of teaching, as it helps students identify their areas of strength and weakness. Landry stated, "We're much more efficient now, and students [are] getting immediate feedback." With this information, teachers can decide how to design their lessons and feedback to meet the needs of each student. Pat supported this by saying:

> As an example on the geometry part of these assessments, ... they get to come with me for extension work, where we're going to be digging a little bit deeper, maybe even looking at some sixth-grade concepts, like, intertwined within the geometry unit I go to the sixth grade Common Core standards and say okay, what are they going to need [to be] preloaded with, in order to be successful?

Michel explained how they would handle the data differently by saying:

> Having the data will enable me to communicate not only with fellow mathematics teachers and students but also with the parents about the areas and skills that students need to improve. I feel that having the data will help me have a more solid discussion with all the relevant groups, including students, parents, and teammates.

The participants' comments showed that adaptive diagnostic assessment tools helped facilitate communication between a teacher and other mathematics teachers, students, and parents. Teachers used the reports generated by the diagnostic tools to seek the opinion of other mathematics teachers on how to improve classroom instruction to enable students to grasp the different mathematics concepts; however, they did not elaborate on this idea. Participants also discussed how the diagnostic assessment tool provided several ways of differentiating the reports to determine the skills that could be used to improve students' understanding of mathematics. Those results suggest that the information obtained from the adaptive diagnostic assessments allowed participants to make decisions on how to design their lessons to meet the needs of each student.

Within pedagogy, customizing classroom instruction was mentioned. As previously discussed, the authors wanted to understand better how the teachers used the assessments to conduct classroom instruction and how the adaptive diagnostic assessment contributed to changing the classroom environment. From participant responses, it was evident that the diagnostic produced significant positive changes. According to Landry, adaptive diagnostic assessment changed how they teach mathematics immensely. They stated:

> We use the information of the diagnostic results to make decisions in the daily programming of our instruction for our students. It changes the classroom setup because students move in or out of the classroom based on their diagnostic scores and results. The scores obtained by students help in the identification of their needs. Its changed [classroom instruction] every day and, specifically, mathematics.

Based on participant statements, it was evident that adaptive diagnostic assessment has positively impacted how teachers conduct their classroom instruction. The diagnostic tools help teachers organize their lessons based on the learning needs of students. This view was supported by Pat, who said:

> The diagnostics give me a place to start. It enables me to place the students into specific groups and customize instruction to meet their needs. It enables me to identify the students who are in need and face greater challenges compared to the other students. At the same time, the diagnostic assessment makes it easy to identify students who need more support and more guidance.

Those comments indicate that in addition to helping teachers plan and administer instruction that meets the needs of students, the adaptive diagnostic assessment helped teachers assess the group dynamics and thus enabled them to customize instructions based on the students' needs. Grouping students is discussed later as a theme; however, it weaves throughout many

participants' responses. According to Jamie, adaptive diagnostic assessment changed how they teach mathematics immensely. They stated:

> I think it makes you look at students a little differently when you know there are certain areas that [students] are struggling in. It makes it easier to address problems ahead of time ... it allows you to adjust your teaching before there are problems or before you do not know the kids are struggling. Again, it helps with group planning. So, ... that's another reason it affects the classroom.

Jamie's statements highlight that adaptive diagnostic assessments have helped teachers better understand their students by understanding their strengths and weaknesses. This enables teachers to customize instruction to address students' learning needs.

Adaptive diagnostic assessments were reported to improve the instructional strategies used by mathematics teachers to convey instructions to students. As such, they have contributed to enhancing the efficiency with which mathematics is taught to students. These sentiments were supported by participant statements, such as when Pat stated:

> By using adaptive diagnostic assessments, we can get results within a short time. They also enable us to get better item analysis from the test, which is helpful in decision-making. Previously, we did the grouping of kids based on common assessments, and the adaptive tests gave us a little bit more depth.

Results show that adaptive diagnostic assessments enable teachers to receive information on students' performance quickly. Stevie added,

> We kind of changed the way we have delivered ... our curriculum for math, and we have seen a pretty big difference in data.

Using the obtained data, teachers can customize instruction to meet the students' needs. Sam stated,

> The diagnostic assessments help you do activities within what we call it skills time, or the stop drop mathematics time, where we're meeting those margins' scripts. It makes that instruction more efficient and better.

The information obtained from Sam illustrates how adaptive diagnostic assessment contributed to enhancing the efficiency of mathematics teachers in delivering instruction and improving understanding among students.

Michel acknowledged the contribution of adaptive diagnostic assessment in enhancing instructional strategies by stating:

> Once we have identified where the greatest need is, we really try to focus our efforts ... thereby defining different ways on how we can reach those different kids ... we usually separate them into three different groups. And then we take a specific skill sometimes, and then we are more direct in our instruction that way to try to bridge those gaps.

Participants' responses indicate that the diagnostic tools help improve the decision-making process, as teachers can identify pedagogical strategies to help improve the ease with which students understand the different mathematics concepts. As a result, teachers can focus their efforts on helping students overcome the challenges they encounter in comprehending mathematical concepts.

Effective Time Usage

The effective use of time for mathematics lessons emerged as a theme. Adaptive diagnostic assessments can provide a means by which the teachers can plan how to deliver instruction to their students and in what amount of time. To demonstrate the importance of the diagnostic assessment in planning time, Pat stated:

> At my school, we have 90 minutes of mathematics. When teaching math, we use about 60 minutes to cover the core aspects of the subject and instruction. Then we use 30 minutes, where the students are placed into groups of about five and six ... We are able, for half an hour every day, five days a week, to give instructions to students about different topics to be learned. By using the diagnostic assessments, I am able to give my students what they need to improve their knowledge in mathematics.

By allowing teachers to identify the areas requiring more instruction, they could consequently allocate more time. Allocation of more time to teach students in weaker mathematical areas could help improve their understanding and overall performance in mathematics. Most participants were comfortable using adaptive diagnostic assessments to plan lesson time requirements. Sam said:

> The data you get can help you determine the speed with which you cover the content in class, and you are almost not even going to know what to do with the amount of extra planning time that you are going to have acting on the diagnostic.

The diagnostic tools allowed teachers to plan and design instruction based on the topics needing to be covered. Based on the reported data, adaptive diagnostic assessments made it easier for the teachers to plan the amount of time spent on the different lessons and activities the students engaged in. Michel specifically said,

> [Adaptive diagnostic assessment] allows us to be more efficient.

Grouping Students

When responses were analyzed to determine how teachers used adaptive diagnostic assessments in their classrooms, grouping students was identified. Discussion on the grouping of students was mentioned many times throughout the participant statements. It appears that how students were grouped and regrouped was a primary benefit of using adaptive diagnostic assessments. Michel indicated that the diagnostic assessment helped by providing reports to assess students' different skills and identify each student's areas of weakness. Stevie agreed with them by stating:

> i-Ready has very good data and provides us with different reports on student progress that can be sent home. The reports can also be assessed to identify the different skills for grouping kids, so it is definitely a good starting point for us.

Sam, who had six years of using adaptive diagnostic assessment in teaching mathematics, indicated that the diagnostic assessment helped them determine groups. They concurred with other participants that it helped in identifying the areas of weakness of each student and stated:

> I use it to determine my mathematics groups and to help me determine who might need enrichment or extra help. I also can look to see where my class as a whole is struggling. Some years, we struggle more in number sense, other years in algebra.

In addition, Jamie said when discussing groups:

> We typically use it [diagnostic assessment] initially to sort kids and what we call wind time, which means someone will take the high group to give them extension work, someone will take the middle group, and someone will take the lower group to do remediation.

This also supports how these teachers in this one school grouped students into ability groups. Thus, they chose to put students at similar levels of understanding together versus mixed abilities. However, teachers could group by spreading out ability levels within a group or other grouping methods. This just happens to be how our six participants typically grouped their students.

Mathematics teachers can use the reports generated by adaptive diagnostic assessments to identify the topics and concepts students have not understood. Based on the participants' comments, the authors concluded that the progress reports supplied by the diagnostic tool can be used to determine each student's level of growth and how well they have mastered the content being taught. The progress reports can then be used to group students based on ability, helping teachers customize instruction based on student's level of understanding. Students can be re-grouped as additional assessments are completed throughout the year.

Changes Over Time

Jamie, who had taught mathematics for 21 years, felt that the data produced by the diagnostic tool had assisted them in becoming more specific when facilitating instruction by identifying specific areas in which students faced difficulty. This allowed them to customize the instruction to improve comprehension of the concepts being taught. They stated:

> I feel like in the past we were not as data driven as we are now. Adaptive diagnostic assessments were therefore not used as much to determine the specific areas that the kids needed to work on it. The diagnostic assessment was used generally to facilitate teaching, unlike currently, where it is a lot more specific. The information obtained is currently used differently to address the specific areas on those assessments.

Based on Jamie's statement, it was evident that adaptive diagnostic assessment positively impacted how teachers identified the strengths and weaknesses of each student. Pat discussed how much more they used the diagnostic assessment tool in frequent years,

> Earlier on when I first started using [diagnostic assessment, it was the] only one that was required of me and maybe once or twice a year, and then three to four times a year, but I am using the tools much more often now.

Thus, the frequency with which adaptive diagnostic assessment is used in classrooms has increased over the years.

Technology Challenges

Technology challenges emerged as a theme for using the adaptive diagnostic assessment to facilitate teaching and learning mathematics. One of these challenges was the inability of the kindergarten students to log in to the adaptive diagnostic assessment tool. Jamie stated:

> In kindergarten, this is not very feasible because [students] have to be able to log in in order to do it. This takes a lot of practice … it is not that valid because many of our kids struggle with the initial use of a Chromebook and navigating a test online.

The feedback provided by Jamie highlighted the difficulty for young children to log in and use it for learning, and even after getting access to the application, students could find it challenging to navigate when required to complete online assessments.

Landry identified another critical challenge associated with the use of adaptive diagnostic assessments:

> Honestly, the challenges all come from the technology side and the actual technology being the barrier to student willingness to use technology appropriately.

Landry also commented on the tool not engaging students, concerned that teachers needed to make fun activities out of logging in and using the tool and that the lack of that could cause students to lose interest in the content being learned. Jamie concurred by discussing the amount of time needed for a student to sit down and take the assessment as too long. They stated:

> The main challenge involves technological issues. Of course, the first time we used it, we did not have the kids use it one-on-one. So, to try and find computer times to give an assessment that takes about three hours was a challenge.

Jamie stated that the application was designed to engage young children for more extended periods (of about three hours), and technology speed issues could limit the pace at which students are taught mathematics. According to Pat, the students also took different amounts of time to work through the assessment, with some taking 40 minutes and others taking four days to do the same amount of assessment. Finding computer time that is flexible enough for each student could be a challenge during the day with other subjects being taught.

Another challenge that emerged was how the adaptive diagnostic assessments presented questions beyond the students' scope and/or level. That meant the results were not a true reflection of the concepts taught in class. This challenge was highlighted by Michel, who indicated:

> A lot of times, the assessments are asking kids questions that we did not even teach or are beyond their grade level. When taken into consideration, it affects the results of the kids. And I think that has been a big challenge for us as well.

To support that, Stevie explained:

> The differences can also be observed in the vocabulary used in the adaptive diagnostic assessments. Usually, they can use terms that are different from what we normally use in the classroom. This has necessitated that we use similar vocabulary with our curriculum vocabulary so that the kids can know the words that are synonymous with each other.

Stevie and Michel agreed that the contents of adaptive diagnostic assessment differed to some extent from the content taught in the classrooms. This was illustrated by the difference observed in the vocabulary used in the diagnostic tools. The students could, at times, find it difficult to understand some of the vocabulary used in the tests, which then impacted their performance. It appears that although some of the vocabulary and concepts with the tool could be customized to a grade level or achievement level, many of the participants were instead adjusting to the tool. This could vary from tool to tool, as the authors only had access to the one assessment tool used by this district.

Given that adaptive diagnostic assessment is gaining widespread importance in teaching mathematics, it was necessary to determine the participants' perceptions regarding the use of this diagnostic assessment. Research question 2 asked: What were teachers' perceptions regarding the use of an adaptive diagnostic assessment in their teaching of mathematics? Participant responses varied, with some exhibiting positive attitudes and others expressing negative attitudes toward using the diagnostic assessment. However, the majority of the participants were satisfied with the critical role played by the diagnostic tool in enhancing the teaching of mathematics. The authors have aligned the responses into two discussions: attitudes toward and benefits of using adaptive diagnostic assessments.

Attitudes

The participants appeared satisfied with the critical role played by the diagnostic tool in enhancing mathematics teaching. For instance, Sam outlined the positive effects of adaptive diagnostic assessment, including the ease of grouping students and monitoring the students' progress. They responded,

> The positives are getting much more. I would not say groups are perfect when we create them using the diagnostic. It allows us to place students much more quickly and more accurately than ever before.

Michel mentioned:

> We look at that data to see how the kids are progressing and where the needs are. And so, once we've identified where the greatest need is we really try to focus our efforts on there by building and defining different ways on how we can reach those different kids, and then we take those kids, and we separate them into groups, since there's three teachers on the fifth-grade team we usually separate them into three different groups. And then we take a specific skill sometimes, and then we're more direct in our instruction that way to try to bridge those gaps.

There was an agreement in the participants' responses that the reports from the diagnostic tools used to group students (based on their level of understanding) were positive. The groups then receive instruction that helps to address their weaknesses and, in the process, helps bring students to similar levels of understanding.

Additionally, Pat stated:

> The use of diagnostic assessment is critical in helping us to improve understanding of the subject among the kids, assess progress made by the kids, and reteach them, where necessary. And even though we know which kids are not at grade

> level by the first set of diagnostics, we're at the beginning of the year. It is nice using diagnostic assessments to monitor the progress of students and to determine the impact of the guided groups. The impact that the guided groups have on the [students] can [then] be monitored throughout the year.

Teachers indicated that adaptive diagnostic assessment helped promote understanding of mathematics concepts for the students. It also allowed teachers to monitor the students' progress. This enables teachers to determine whether their teaching strategies have a positive impact on improving the understanding of mathematics among students.

Just like Pat, Sam expressed positive sentiments about the diagnostic assessments for ensuring effective coverage of the content:

> I feel i-Ready covers a lot of work during teaching. It contains content that is covered across the different districts and states. This helps to limit the disadvantage experienced by kids who move across different districts or even different states.

Jamie indicated their positive attitude towards the adaptive diagnostic assessment' reports as they were easy to understand and easy to share with parents. They said:

> The diagnostic assessment shows growth, and it shows deficits in [a] very simplistic and easy-to-understand manner. I think that it makes it easy to speak to parents about where the kids are and the growth that they've made. It's also really good for showing the kids the progress that they have made. It is really good for goal setting because when we show them their scores and after each test after April or August and December, we set a goal for the next benchmark testing, and so it does motivate the kids. Also, by using i-Ready, students are able to identify the lessons they can do in between, including those that they do not always love or are challenging, but it is a motivator for them to do more once they can see where they were. And it's also good because it pushes your higher kids to go higher, because then they know, well, if I'm doing my lessons I'm getting some fifth-grade lessons when I'm in fourth grade and it's a motivator for them.

Despite the significant benefits associated with adaptive diagnostic assessment regarding enhancing the teaching of mathematics in elementary classrooms, Sam outlined one significant shortfall of the diagnostic assessment: the difference in the concepts assessed by the diagnostic tool compared to the concepts contained in the curriculum. They stated:

> Usually, different states may have different curriculum. Even though diagnostic assessment has been customized to align the curriculum of some states, others still lag behind in the use of adaptive diagnostic assessment. Therefore, if kids move from states that have not incorporated i-Ready in their teaching to those that have incorporated diagnostic assessment, the kids may get low scores due to the curriculum difference. This will therefore not give an accurate representation of their mathematical knowledge.

Sam indicated that in most cases, there is a disparity between the content in the diagnostic assessment tools and the content taught to students in the classrooms. As a result, students may be disadvantaged, especially when they relocate to different states. The disparity in the content contained in diagnostic assessment tools and taught in classrooms may produce outcomes not reflective of the student's level of comprehension.

Benefits

Adaptive diagnostic assessment has been described as an important tool that helps mathematics teachers facilitate teaching and learning. To begin with, adaptive diagnostic assessments allow mathematics teachers to plan meaningful and efficient instruction. With adequate information on the areas of students' weakness, the teachers could customize their lessons to meet the students' needs and ensure students experienced improvement in their performance. Participants felt the adaptive diagnostic assessment could be used to identify the best strategies for teaching students to ensure they accurately understood the mathematics concepts.

One critical aspect that was discussed was the benefit of using adaptive diagnostic assessment for the participants. Most participants benefited from the ease of using the application and its effectiveness in evaluating students' mathematics comprehension. This aspect was highlighted by Landry, who stated:

> The adaptive diagnostic assessments make it easy to grade and evaluate students on their comprehension of the different contents taught in class. I would not go back to grading by hand and taking hours to create a test that can be generated by a computer within seconds...It provides useful information by performing an analysis of the different items. It is awesome, and I would not go back to carrying out teaching without it.

According to Landry, adaptive diagnostic assessment facilitated the creation and delivery of the assessment and monitoring of students' progress. Unlike past manual methods of assessment that were cumbersome and time-consuming, teachers could obtain data within the shortest time possible to customize instruction to meet students' needs. Pat responded:

> I get a very quick snapshot of where my students are in the process of mastering the various mathematics concepts. I would say that in the past years, it was only possible to determine the progress made by the students towards the end of the unit. Now with the introduction of [the] diagnostic, I can determine the progress of students weekly if I want it. The diagnostic assessment tool helps me to identify where my students are in the process, and I can gear my instruction to them.

Participants agreed that they benefited from the simplicity in design and ease of use of the diagnostic tool, which enabled them to monitor students' weekly progress. The adaptive diagnostic assessments provided an overview of individual students' performance, thus enabling the identification of areas of strength and weakness. Landry outlined its significance in helping students with disabilities grasp the contents being taught. They stated,

> It's definitely helped all students, and actually, I see that it has an impact on students with cognitive disabilities or physical disabilities when they're given adaptive tools, especially in mathematics.

Diagnostic assessment tools have been customized for ease of use for students with cognitive and physical disabilities. This can help to ensure that students with disabilities or other special needs are not discriminated against or disadvantaged in learning mathematics.

DISCUSSION & IMPLICATIONS

The primary goal of this case study was to expand on existing research to understand how adaptive diagnostic assessments help teachers modify and thus improve teaching and learning in mathematics. Adaptive diagnostic assessment can be a critical tool designed to provide teachers with actionable information about the learning needs of each student. Even with the few weaknesses found regarding the tool, the findings of this study adequately supported incorporating adaptive diagnostic assessment tools into mathematics education.

This case study identified various benefits associated with using adaptive diagnostic assessment in teaching mathematics. The arguments presented by the different study participants showed that using diagnostic assessment tools allows teachers to adapt their instruction and classroom environment and better meet the learning needs of their students (Koehler et al., 2013; Niess et al., 2009). Teachers can use diagnostic assessment tools to improve classroom instruction by making learning more group-based. Guided groups could help improve students' communication and problem-solving skills in learning different mathematics concepts. As studies have shown, communication during mathematics education and problem-solving skills in groups can lead to better mathematical understanding (Tambunan, 2019). Findings show that adaptive diagnostic assessments helped in the determination of group dynamics, including the identification of groups that need more enrichment. This information is vital, as teachers can use it to identify strategies to promote learning in each group and improve teachers' efficiency in providing immediate feedback to students on their performance. Teachers receive data about the areas, where students need additional learning support (Chang, 2015; Shute et al., 2006). The data also identify areas of mathematical strengths and weaknesses, which can allow for the initiation of troubleshooting measures to identify the most suitable approaches to improve student comprehension. The data generated from the assessments helped teachers use the assessments to determine classroom instruction and contribute to improving the classroom environment, which is supported by literature (Black & William, 2003; Guzmán & Conejo, 2015; Hedegaard, 2005). Most of the teachers could use the data provided by the tool to identify the mathematical content that required more instruction and consequently allocate more lesson time. Although not mentioned, perhaps having "hard data" helped the teachers communicate with other teachers, parents, and administrators. This could lead to increased communication about individual students' achievement.

The diagnostic assessment tool was reported to help teachers improve their classroom instruction by identifying the students' needs and allowing teachers to customize the lessons to address those needs. Teachers could use diagnostic results to set a personalized learning path for each student. This allowed the teachers to work on instruction that matched the unique learning needs of their students. The findings of studies conducted by Shute (2008) and Shute and Kim (2014) support the views of the teachers involved in the current study. They reported that feedback is an important component of diagnostic assessments and helps guide instruction (Shute, 2008; Shute & Kim 2014). Teachers can get feedback about the areas in which students need improvement, which can be used to support learning. For example, the assessment tool can provide teachers with information on readiness that indicates whether students are ready for a new lesson. It also indicates the level of understanding of the concepts already covered.

With regard to pedagogy, the study findings showed that adaptive diagnostic assessment can be used to facilitate the teaching of mathematics. Teachers can use the diagnostic tools to devise instructional approaches that can improve instruction based on the needs and weaknesses of students, which is supported in the literature (e.g., Bohlmann & Fletcher, 2008; Ketterlin-Geller & Yovanoff, 2009; Shute et al., 2006). The reports and feedback provided by adaptive diagnostic assessment can be used by teachers to make decisions on how to design their lessons to ensure that the needs of all students are addressed. This is supported by Antoniou and James (2014), who conducted a study exploring the importance of formative assessment for enhancing learning in classrooms. The common agreement is that teachers can use the assessment for various purposes, including sharing learning intentions, directing classroom instruction and other learning tasks, and providing feedback to enhance student learning. These features facilitate the ease with which teachers identify the appropriate strategies to enhance the teaching and learning of mathematics (e.g., Antoniou & James, 2014; Koehler & Mishra, 2008).

There was a common consensus among the teachers that the adaptive diagnostic assessments improved their classroom instruction by identifying student needs and allowing the teachers to customize the lessons to address student needs. Also, the adaptive diagnostic assessments helped the teachers make decisions on how to design instruction. The diagnostic assessment tool helped inform lesson content and improve pedagogy used in mathematics classrooms. Clark (2008) stated that with diagnostic assessments, teachers can enact open and inventive learning strategies in their classrooms, which have the potential to improve learning. There was a common agreement among the teachers that adaptive diagnostic assessments provided reports

that could be used to assess students' different skills. The diagnostic tools provided information that showed teachers, where students had gaps, thus enabling the planned instruction to address the existing gaps. Also, the tools helped teachers develop improved instructional techniques and determine how to integrate technology into classroom instruction better. In addition, there was a common consensus among the teachers that adaptive diagnostic assessments are becoming more specific and customized for ease of use by students. The teachers reported using the assessment often to guide instruction in their classroom. In supporting the positive attitudes exhibited by teachers toward adaptive diagnostic assessments, a study by Ketterlin-Geller and Yovanoff (2009) identified diagnostic assessments as an emerging solution for providing accurate and detailed information regarding the level of students' understanding of mathematics and the specific needs of learners.

This study examined the teachers' perceptions regarding the use of adaptive diagnostic assessments for enhancing the teaching and learning of mathematics in elementary classrooms and found that the teachers had a positive attitude toward the adaptive diagnostic assessments and were satisfied with its significant contributions to enhancing the teaching and learning of mathematics. The findings from this study showed that the teachers were satisfied with the benefits offered by adaptive diagnostic assessment tools for enhancing the teaching and learning of mathematics. This view was supported by Roberts and Gierl (2010), who indicated diagnostic assessments have distinct features that make them appealing for use by teachers to enhance teaching and learning. Roberts and Gierl (2010) reported that adaptive diagnostic assessments provide diagnostic feedback that guides teachers and students in the teaching and learning processes. The teachers stated that diagnostic assessments provide a quick visual summary of the performance of each student and a means by which to improve instruction (Nikolov, 2016; Shepard, 2000). Another reason the teachers expressed a positive attitude toward adaptive diagnostic assessment was that it helped improve the approaches they could use to teach mathematics to students facing difficulties (Allal & Lopez, 2005). The assessment tools were found to regulate teaching and learning through interactive assessments and by the use of tools that can be adapted to classroom practice.

One benefit briefly identified was the use of the adaptive diagnostic assessment in helping students with disabilities better understand the concepts being taught in class (Shute et al., 2006). The teachers were also motivated to use the assessment because it contained easy-to-use features that facilitated instruction among students with disabilities. More research into this aspect of adaptive diagnostic assessments is needed.

A study by Ozudogru and Ozudogru (2019) acknowledged that technology currently plays a critical role in enhancing classroom instruction and improving students' motivation and engagement. This study advocates for teachers to use technology and diagnostic assessments to improve their teaching methods and increase the involvement of students in mathematics. The six teachers in our study suggested that other teachers should learn how to use adaptive diagnostic assessments to make it easy for the teachers to plan the time spent on the different lessons and activities in which the students engaged.

Despite the significant benefits associated with an adaptive diagnostic assessment, the participants identified various challenges that limited its effective use in the classroom, including the inability of the young students to log in and use the diagnostic assessment effectively, difficulty in navigating through the online tests, and disparity in students' rates completing the assessments. There was consensus among the participants that the main challenge associated with the use of adaptive diagnostic assessment was linked to the technological aspects of the tool. The participants suggested that new teachers should learn how to use the adaptive diagnostic assessment to make it easy to plan time spent on the different lessons and activities in which the students engaged. The teachers reported that they used diagnostic assessment to frame their lessons and allocate time based on different activities to be carried out in class. With adaptive diagnostic assessment, teachers completed the content quickly and were more efficient with instruction.

Findings showed significant improvements to adaptive diagnostic assessment have been made over the years to enhance its potential to promote teaching and learning. Diagnostic assessment has become more specific, and more features have been incorporated to make it easier for elementary-level students to navigate. It also contains more graphics and pictures, making it easy for students to grasp mathematics concepts. The teachers found the diagnostic assessments to be beneficial for improving teaching and understanding of mathematics. Bohlmann and Fletcher (2008) supported the significant role played by diagnostic assessments for promoting mathematics teaching by indicating the assessments provide teachers with instruments that can be used to develop formative assessments. Finally, existing studies reported diagnostic assessment allows teachers to identify the strengths and weaknesses of learners regarding the topics and skills taught (e.g., Bohlmann & Fletcher, 2008; Gierl et al., 2008; Nikolov, 2016; Shute et al., 2006) and can be used by teachers to improve student learning.

The findings of this case study illustrate the importance for schools to adopt adaptive diagnostic assessments to improve pedagogical practice and promote mathematics learning among elementary-level students. With the ongoing technological advancement, it is expected that improvements will be made to diagnostic assessment tools to make them even more efficient in promoting instruction. However, the authors caution that implementing any new tool or technology needs sufficient teacher professional development opportunities for teachers to succeed. Finding examples of exemplary pedagogy using adaptive diagnostic assessments may be difficult, but looking at this case, we can also envision it happening elsewhere.

Limitations

As with any social science research study, there are limitations to the research. The main limitation of this study was the small sample size. The data were limited to one district school, which limited the generalizability of the findings to other school districts. The small sample size, however, might have supported the teachers' experiences as expressed by the participants. The study was also limited by the voluntary participation of the teachers. This might have introduced bias into the results. In addition, the tool itself was provided by the school administration without input from the teachers.

In addition, this study was conducted during COVID-19, and as such, there were limitations in the ability to collect data and the reduced number of participants than had originally been planned. Many of the participants who completed the survey were then uncomfortable doing interviews and focus groups.

Another limitation was related to unanswered questions of the researchers. We attempted to dig deeper into some of the ideas presented after the research had concluded and this article was being written, but we could not get responses from participants. Thus, we cannot answer some questions, such as if there were any other tools or methods teachers used in conjunction with the diagnostic assessments to determine student groupings. How did students respond to being grouped and re-grouped? What challenges did the teachers face when grouping students? With the influx of artificial intelligence (AI), have the diagnostic assessment tools changed? Are there new AI tutoring systems in place? This would be a great starting point for future research.

Future Research

Future research could include a focus on mathematics teachers drawn from diverse school districts. This would help enhance the reliability and generalizability of the study findings. Future studies should attempt to be all-inclusive and cover teachers from all levels (from kindergarten to high school). This could determine if any variations in the study's outcomes exist at different grade levels. In addition, future research could focus on expanding this study to examine parents' perceptions of the use of adaptive diagnostic assessment in teaching and learning. As previously mentioned, the use of AI in education has led to new tools and technologies available for schools. We wonder how this technology has affected the diagnostic assessments–have they gotten better at meeting the needs of the curriculum and/or the vocabulary used by the teachers?

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APPENDIX A

Interview Questions

1. Tell me a bit about your history using adaptive diagnostic assessment in your teaching of any subject. Has it always been mathematics, or have you used it in other subjects?
2. Has the use always been with technology (web-based or technology-enhanced)?
3. Can you describe your past and present use (if applicable) and how they have differed?
4. Let's talk specifically about the use of adaptive diagnostic assessment in your teaching of mathematics–What motivates you to use adaptive diagnostic assessment in your teaching of mathematics?
    a. Probe-administration, you learned about it in school, you saw another teacher using it, you saw it at a professional conference, professional development, etc.
    b. How do you feel about using it? Can you describe your attitudes towards the tool?
5. Tell me about the first time you used adaptive diagnostic assessment in a mathematics class. What were the challenges you faced?
    a. How have those challenges changed over time?
    b. If you had that first time to do over again, what would you tell yourself to do differently?
6. How often do you use adaptive diagnostic assessments currently in a mathematics class?
7. Can you describe how adaptive diagnostic assessments are currently used in the classroom? What is the process?
8. How do you feel about using adaptive diagnostic assessment tools in the mathematics classroom?
9. What do you think are the best parts of using adaptive diagnostic assessment in mathematics?
    a. What are the positives?
    b. What are the negatives to using adaptive diagnostic assessments in the mathematics classroom?
10. Do you feel there are any advantages to using adaptive diagnostic assessment in mathematics versus not using the tool?
    a. What do you feel are the disadvantages of using adaptive diagnostic assessment in mathematics?
11. Please describe how using the adaptive diagnostic assessment has changed your classroom environment.
12. How does using the adaptive diagnostic assessment get incorporated in your planning time?
13. How does using the adaptive diagnostic assessment get incorporated into classroom instruction? Does it?
14. How do you think the students see the adaptive diagnostic assessment being used?
    a. Do they notice it or is it just routine for them?
    b. Do you know what level of mathematics students first see it introduced in the classroom?
15. How do you feel using the adaptive diagnostic assessment changes your pedagogical (instructional strategies) practice in mathematics? Does it?
    a. What do you differently because you have the assessment results that you would not typically do if you did not have it?
    b. What can you do now because of it? Anything different in teaching?
    c. Does it prevent you from doing anything you'd like to do pedagogically?
16. What concerns do you have regarding adaptive diagnostic assessment tools in the mathematics classroom?
17. Please describe the biggest barrier to using adaptive diagnostic assessment in mathematics.
18. If it was not offered as a tool, what would you do differently in your classroom?
19. How has the use of adaptive diagnostic assessment influenced your teaching mathematics?
20. How has the use of adaptive diagnostic assessment influenced your curriculum development?
21. Do you believe that your use of adaptive diagnostic assessment helps your students?
    a. All students or only students in certain classifications? (disability, slow learner, gifted learner, etc.)
    b. If so, in what ways?
22. What do you feel are the challenges facing the implementation of adaptive diagnostic assessment tools in mathematics?
23. Are the teachers required to use the adaptive diagnostic assessment to enhance teaching and learning in mathematics classrooms?
    a. Does the school district force you to use the adaptive diagnostic assessment in the mathematics class?
24. What are your future goals/plans for using adaptive diagnostic assessment in mathematics?
25. Do you have any suggestions or advice for elementary mathematics teachers considering the use of adaptive diagnostic assessment tools?

APPENDIX B

Link Between Research Questions, Emergent Codes, Themes, & Subthemes

Table B1. Link between research questions, TPACK, themes, & sub-themes

RQ	Code	Themes/sub-themes	Description
Q1	TCK	Assessment usage	*Teachers used diagnostic assessment for instruction.*
			"Knowledge of what technologies are the best for specific content" (Koehler & Mishra, 2009).
		Grouping students	*Teachers used the diagnostic assessment to group the students based on the skill level of learners.*
	CK		*"Knowledge of the actual subject matter that is to be taught" (Koehler & Mishra, 2008, p. 13).*
	TK	Deeper knowledge	*The teacher used the assessment to understand more deeply what they need to teach.*
			"Enables a person to accomplish a variety of different tasks using information technology" (Koehler & Mishra, 2008, p. 15).
		Challenges	*Challenges associated with the use of the diagnostic assessment.*
	TPK		*"Knowledge of how teaching & learning changes when particular technologies are used" (Koehler & Mishra, 2008, p. 16).*
		Classroom instruction	*Teachers used the assessments to conduct classroom instruction.*
	PK		*"Knowledge that applies to student learning, classroom management, lesson plan development and implementation, and student evaluation" (Koehler & Mishra, 2008, p. 14).*
		Planning time	*Teacher use the assessment to improve their lesson plans.*
	PCK		*"The transformation of the subject matter for teaching" (Koehler & Mishra, 2008, p. 14).*
		Instructional strategies	*Techniques teachers use to direct instruction and enhance teaching and learning.*
	TPACK		*"A framework utilized to describe and understand knowledge needed to execute effective pedagogical practice in a learning environment that is technologically enhanced" (Koehler & Mishra, 2008).*
		Past & present use	*Determine if there were differences in teaching and learning mathematics when using the assessment.*
Q2	TA	Teachers' attitude	*Identify the teachers' beliefs and experience.*
		Positive	*The advantages of the assessment in teaching and learning.*
		Negative	*The disadvantages of the assessment in teaching and learning.*
		Benefits	*Teachers' benefits of the use of the assessment in teaching and learning.*