A Pilot Study of a Self-voicing Computer Program for Prealgebra Math Problems

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Abstract: Fourteen students with visual impairments in Grades 5–12 participated in the field-testing of AnimalWatch-VI-Beta. This computer program delivered 12 prealgebra math problems and hints through a self-voicing audio feature. The students provided feedback about how the computer program can be improved and expanded to make it accessible to all users.

There is growing awareness that success in algebra is an important component of students' educational programs. Many states now require students to pass algebra to graduate from high school (American Diploma Project, 2010; National Mathematics Advisory Panel, 2008). Students who are not successful in algebra classes are underprepared for many college majors and are less likely to enter the science, technology, engineering, and mathematics (STEM) fields (Crisp, Nora, & Taggart, 2009; Kaylor, 2010; Tyson, Lee, Borman, & Hanson, 2007). Some educators have even identified algebra as a civil rights issue, arguing that all students need to be ensured the opportunity to master algebra skills to have full access to a range of career opportunities (Martin, 2000; Moses & Cobb, 2001).

The ability to solve word problems is considered to be an essential component of proficiency in mathematics (Kintsch & Greeno, 1985; Koedinger & Nathan, 2004; National Council of Teachers of Mathematics, NCTM, 2000) and therefore is an essential skill for success in prealgebra. Finding a way to increase the ability to solve word problems of middle school students was the impetus behind the development of AnimalWatch, a graphical web-based tutoring system. The AnimalWatch system helps students build skills in computation, fractions, and prealgebra math skills that provide an important foundation for success in algebra. All materials are aligned with the well-respected California Mathematics Content Standards (California State Board of Education, 1997) and the *Principles and Standards for School Mathematics* of the NCTM (2000).

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Students who use AnimalWatch solve a series of word problems about endangered and threatened species as a way to connect math learning with authentic science information. Currently, more than 800 word problems are available for teachers to use with their students on such topics as the great white shark, Takhi wild horse, giant panda, and snow leopard. Each word problem includes interactive hints, worked examples, and video lessons that students can access on request to guide them to and through the appropriate steps to a solution. Data on students' responses are tracked by the computer and made available to teachers for review. Although not accessible to students with visual impairments (that is, those who are blind or have low vision), AnimalWatch has been effective in increasing the math performance of sighted students in Grades 5–8 (Beal, Adams, & Cohen, 2010; Beal, Arroyo, Cohen, & Woolf, 2010). Additional information may be found at the project's web site <www.animalwatch.org>.

Research has shown that the mathematics problem-solving performance of sighted students often falters when cognitive resources are sapped by anxiety, time pressure, learning disabilities, or other factors (Osborne, 2007; Royer, Tronsky, Chan, Jackson, & Merchant, 1999; Swanson, Cooney, & Brock, 1993; Swanson & Jerman, 2006; Sweller, 1988; Walczyk & Griffith-Ross, 2006). It therefore seems reasonable to predict that when students who are visually impaired have to struggle to access material because it is not fully accessible or do not have complete conceptual understanding of information from a story problem, they will have fewer cognitive resources available to focus on the mathematical aspect of solving problems.

Consistent with this prediction, research has shown that students with visual impairments have lower rates of achievement in mathematics than do sighted students and participate less in the STEM fields (Cavenaugh, 2006; National Science Foundation, 2009). More than a decade ago, Senge (1998, p. 3) stated that "the majority of students with visual impairments entering postsecondary education lack the literacy and technical skills necessary to successfully manage the challenges of mathematics or sciences in higher education."

The impact of visual impairment is widely recognized to be particularly significant for mathematics learning (Cavenaugh, 2006; McDonnall, Geison, & Cavenaugh, 2009; National Science Foundation, 2009). Vision provides access to important information that supports the development of conceptual understanding in mathematics. As Dick and Kubiak (1997, p. 344) stated:

> Describing and categorizing direction, quantity, shape, and logical attributes are at the heart of mathematics. Much of the language of mathematics relies heavily on visual reference. Descriptions of mathematical concepts that appeal to visualization may enjoy immediacy for the sighted student, but they require significantly more cognitive processing for the visually impaired. . . . More than for any other sense, the impairment of sight poses the most difficult challenges to learning mathematics.

Helping students with visual impairments master core prealgebra topics, such

Table 1
Demographic data for the 14 participants.

Participant	Grade	Gender	Educational placement	Grade level for math	Primary reading medium
Matt	5	Male	Public	2 years below	Braille
David	6	Male	Residential	3+ years below	Braille
Lorenzo	6	Male	Residential	2 years below	Braille
Ellen	7	Female	Public	On grade level	Braille
Steven	8	Male	Public	3+ years below	Braille
Nathan	8	Male	Public	On grade level	Braille
Heather	8	Female	Public	On grade level	Braille
Danielle	8	Female	Public	2 years below	Braille
Robin	8	Female	Public	1 year below	Large print
Morgan	8	Male	Public	Above grade level	Braille
Pam	9	Female	Residential	3+ years below	Braille
Tom	10	Male	Residential	3+ years below	Braille
Melissa	11	Female	Public	On grade level	Print
Rosa	12	Female	Residential	3+ years below	Braille

as those addressed in AnimalWatch, led to the funding of a National Science Foundation grant in 2007 (HRD 0725917/0940201). In the initial phase of this project, 32 word problems from the AnimalWatch program were made accessible through the commercial screen-reading program JAWS. Eleven students in California field-tested this version of AnimalWatch, which was dubbed Animal-Watch-VI (Beal & Shaw, 2009). Although the students could use the program, they did not receive any instructional support from the computer program or the researchers when they had difficulty solving the word problems. Also, the field-testing revealed that the students had many challenges operating JAWS, and, in some cases, the school's computers were running an older version of JAWS than the version used to develop AnimalWatch-VI.

To address some of these limitations, another version of AnimalWatch-VI, dubbed AnimalWatch-VI-Beta, was developed. This version provided the participants with audio hints for word problems and used an internal self-voicing program. This article reports the results of using the AnimalWatch-VI-Beta system with 14 students with visual impairments. The research was approved by the Institutional Review Board of the University of Arizona.

Methods

Participants

The study included a convenience sample of 14 students with visual impairments, who were recruited at the Arizona State Schools for the Deaf and Blind (ASDB), through teachers of students with visual impairments who were known to the second author, and through contacts that the second author had with families of students with visual impairments in Tucson. Demographic information about the participants is presented in Table 1. (Fictitious first names are used to protect the students' privacy.) The sample included students who attended the ASDB residential program in Tucson, students from two school districts in Tucson, and students from four school districts in Phoenix.

Students' educational records were not reviewed; therefore, the teachers of students with visual impairments or the parents provided information about the primary reading media that the students used during their math classes. In addition, the teachers or parents were asked to indicate whether the students were performing above grade level in math class, on grade level, one year below grade level, two years below grade level, or three or more years below grade level.

Instruments

AnimalWatch-VI-Beta

AnimalWatch-VI-Beta is a web-based computer program containing 12 word problems. Each problem is presented via audio using a self-voicing program. Audio files for the problems were generated from the electronic word problem text using the "say" program included in the Macintosh (Mac) OSX operating system. The voice selected for use in AnimalWatch-VI-Beta was "Alex." The "say" program creates a ".aiff file," which was then converted to an mp3 file using the iTunes program in Mac OSX. The mp3 files were added to the AnimalWatch-VI-Beta database.

The 12 word problems are divided into three sets of four problems each on the basis of the difficulty of the required math operations. One set included four easy problems about the Takhi wild horse that require addition and subtraction operations. Another set had four hard problems about the critically endangered North Atlantic right whale that required the division and subtraction of fractions with unlike denominators. Another set comprises four medium-difficulty problems about the giant panda that require students to form a fraction, identify a numerator or denominator, and perform simple like-fraction operations. Examples of problems are shown in Box 1. These topics are aligned with the grade expectations for Grade 5 (arithmetic and subtraction operations) and Grade 6 (fractions operations) as outlined in the California Mathematics Content Standards (California State Board of Education, 1997).

The difficulty of the problems was established in two ways: First, the California Mathematics Content Standards (California State Board of Education, 1997) indicate that addition and subtraction operations should be mastered before fractions operations. Within fractions topics, such concepts as understanding the relationship of the numerator and denominator are introduced before concepts involving operations with unlike denominator fractions. Second, prior empirical work had been conducted with sighted students who had completed the same math problems in the original AnimalWatch system. These students' performance was evaluated in terms of the percentage of correct answers and the number of incorrect answer attempts on each problem. The results confirmed that the students' performance was significantly better on the easy problems than on the medium-difficulty problems and was the poorest on the hard problems (Beal & Shaw, 2009).

The AnimalWatch-VI-Beta program now includes two audio hints for each of the 12 word problems. The first hint provides a short explanation of the math operation required for the problem (for example, "This is an addition problem"), and the second hint provides additional information (for instance, "You need to

Examples of easy, medium-difficulty, and hard word problems with hints

Easy (subtraction of whole numbers)

Introduction: In the next problem, you will compare the genetics of Takhi horses and humans.

Problem: Chromosomes are structures in the body's cells that tell it how to grow. Takhis have 66 chromosomes in their cells. Humans have only 46 chromosomes. How many more chromosomes does a Takhi have than a human?

Hint 1: This is a subtraction problem.

Hint 2: Start with 66 and subtract 46.

Medium difficulty (form a fraction)

Introduction: Imagine that you have arrived in China and are at the Wolong Nature Reserve high in the mountains. You will go with scientists who are tracking wild pandas. Scientists look for clues, such as panda droppings and trees where bark has been rubbed off. These clues tell them a panda is nearby.

Problem: Every morning, you go up the mountain with a group of researchers. Your goal is to make an estimation of the number of pandas there are in the reserve. Your group has observed 15 pandas today. You have counted a total of 38 pandas since you arrived in Wolong reserve. What fraction of pandas have you counted today compared to the total pandas you have counted since you arrived in Wolong?

Hint 1: Think about 15 as a part of the total. The part is the numerator, and the total is the denominator.

Hint 2: Form the fraction with 15 as the numerator and 38 as the denominator.

Hard (subtraction of fractions with unlike denominators)

Introduction: Whales sometimes jump part of the way out of the ocean. This behavior is called "breaching." The whale makes a loud splash when its body falls back into the water.

Problem: The splashing that a whale's breaching makes can be heard from 3/4 miles away. However, you are flying 5/6 miles away from two whales that are breaching together, and you can still hear them! From how much farther can you hear the breaching of these two whales compared to what is usual for one whale?

Hint 1: Find the common denominator for 5/6 and 3/4.

Hint 2: Express 5/6 and 3/4 with a denominator of 12, and subtract.

Box 1

express both fractions with a common denominator. Find the common denominator for 12 and 15").

In the session, the problems were completed in a fixed order. The students first completed the easy problems about the Takhi horse, then the hard problems about the right whale, and ended with the medium-difficulty problems about the giant panda. This order was adopted so that the students would be presented with the most difficult problems after they had some experience with the interface but before fatigue would become a potential problem.

Program tutorial

The students begin their session with the program by completing a short tutorial to familiarize themselves with the operation of the interface. They learn to press "p" to play a problem again, "g" to give up, "a" to hear the first hint, "b" to hear the second hint, "c" to clear an answer, and so forth. They are then guided to press the space bar to begin the first problem in the easy set, and can progress through the 12 problems at their own pace, replaying a problem as many times as they want to and accessing the hints as often and when they like. If they do not correctly solve the problem after the third attempt, they are automatically moved on to the next problem. The program does not allow backtracking to revisit completed or skipped problems or forward progression to preview problems. The program records the students' actions with the interface (correct answers and incorrect answer attempts, replays of the problem and hints, and latencies), providing rich electronic data to support the analysis and evaluation of students' behavior (Cohen & Beal, 2009).

Field notes

As each student completed his or her session with the computer program, members of the research team took field notes. These notes were compiled for each student to provide an anecdotal record of the students' comments, tools used when solving the problems (such as an abacus or portable notetaker), and feedback that the students provided about the computer program.

Session format

Each student met with the research team one time. Two students completed their sessions in their homes. The remaining students completed their sessions at their school sites. All the students worked with the Tucson-based research team, comprised of the first two authors and a computer programmer who was present to assist with any technical issues that arose. The programmer had no previous experience with students with visual impairments. The teachers of students with visual impairments were present in the role of observers for 6 of the 14 students. The other 8 students met with the researchers with no other individuals present. The sessions lasted 20 to 50 minutes, depending on the amount of time it took for introductions, computer setup and troubleshooting needs, students' proficiency with the math concepts, and the amount of feedback that the students provided the research team during and after the sessions.

At the beginning of the session, we told the students that AnimalWatch-VI-Beta is a beta version of a computer program that we plan to develop and expand with future funding, we would not be evaluating the math skills or proficiency of the students, we would like the students' feedback about the usefulness of the two hints per problem and how we can improve the program and make it accessible to all students. After a student completed the math problems, one member of the research team asked him or her for comments about the program, as well as suggestions for improvement. The interview was informal rather than semistructured.

Table 2
Mean proportion of correct answers and incorrect answer attempts per problem.

Participant	Easy correct answer	Easy incorrect tries	Medium correct answer	Medium incorrect tries	Hard correct answer	Hard incorrect tries
Matt	1.00	0.25	–	–	0.50	0
David	0.25	1.5	0.75	0.5	0	0
Lorenzo	1.00	0	1.00	0	0.50	0.25
Ellen	1.00	0	1.00	0	0.50	0
Steven	1.00	0.25	1.00	0	0.75	0
Nathan	1.00	0	1.00	0	0.75	0.25
Heather	1.00	0.5	1.00	0.25	0.50	0.25
Danielle	1.00	0.25	–	–	0.25	0
Robin	1.00	0.25	1.00	0.25	0.25	0
Morgan	1.00	0	1.00	0.25	0.75	0
Pam	1.00	0.5	0.75	0	0.75	0
Tom	1.00	0.5	0.75	0	0.25	0
Melissa	1.00	0.75	1.00	0.25	0.75	0.75
Rosa	1.00	0.5	1.00	0	0.25	0
M	0.90	0.375	0.92	0.125	0.48	0.107

Results

Completion of math problems

As the students solved the word problems, their actions with the computer were automatically recorded by the AnimalWatch-VI-Beta program. Captured actions included whether the correct answer was entered for the problem (1 for the correct answer, 0 if the correct answer was not entered), if the problem was answered incorrectly (up to three attempts per problem), the number of times the audio file for the problem was played (1 or more per problem), and the number of times each audio hint was activated (0, 1, or more). These data were subsequently extracted for analysis.

The mean scores for the correct answers and number of incorrect answer attempts per problem are included in Table 2, with the scores shown separately for the easy, medium, and difficult problems. As may be seen in Table 2, two participants did not complete the medium-difficulty equations because of problems with the school's computer network. Therefore, the mean scores for the medium-difficulty problems were computed for 12 participants. The mean scores for the easy and hard problems were computed for 14 participants.

As may be seen in Table 2, the students did well on the easy and medium-difficulty problems, getting over 90% correct. However, they were less likely to enter the correct answers for the hard problems; the average score for hard problems was 0.48 (meaning that they got about half the hard problems correct). With regard to the mean number of incorrect answer attempts per problem, the average for the four easy problems was 0.375 incorrect answer attempts per problem, compared to 0.125 for the medium-difficulty problems and 0.107 for the hard problems.

Table 3 includes the data representing the mean number of times that the audio

Table 3
Mean audio problem activations and hint activations per problem.

Participant	Easy problem plays	Easy hint plays	Medium problem plays	Medium hint plays	Hard problem plays	Hard hint plays
Matt	2	1.5	–	–	1.00	1
David	1	0.5	1.00	0.75	1.00	0
Lorenzo	1.25	0	1.25	1.25	1.25	2
Ellen	1.50	0.5	1.00	0.75	1.25	1.5
Steven	1.25	3	1.00	2	1.00	1.5
Nathan	1	0	1.00	0	1.25	1.5
Heather	1.25	0.5	1.25	1.25	1.25	1.75
Danielle	1.50	0	–	–	1.25	1.5
Robin	1.25	1	2.00	1.25	2.00	0.25
Morgan	1.25	1	1.50	0.5	1.25	1
Pam	1.75	2.5	1.00	1.75	1.00	2
Tom	2.00	1.75	1.00	1.5	1.00	1
Melissa	1.25	0.5	1.25	1.25	1.50	2
Rosa	1.25	1.5	1.25	1.25	1.50	0.75
M	1.46	1.02	1.21	1.12	1.28	1.26

file for each word problem was played. The students had to listen to each problem at least once, so scores of more than 1 indicate that the students listened to the problem a second or third time. The mean scores were similar for the easy, medium-difficulty, and hard problems. The scores may be slightly higher for the easy problems because on several occasions the researcher reminded a student that he or she could listen to the problem again and encouraged him or her to try the replay feature.

Table 3 also shows the mean number of hints that were played per problem. There was a slight trend for more hints to be activated as the problems became more difficult. This tendency might have been even stronger if the students had not had the option to indicate that a difficult problem was too hard (that is, to skip the problem).

We investigated whether students who were struggling in math, based on the ratings by their teachers of students with visual impairments or parents, were more likely to listen to the hints. For the easy problems, we fit a regression model using students' math proficiency, as reported by their teachers or parents, to predict the total number of hints that were activated on the four easy problems. The bivariate fit was significant, $F(1,13) = 5.239$, $p < .05$, indicating that students with weaker math skills used more hints. There was also a significant relationship between students' math proficiency and the total number of hints utilized on the medium-difficulty problems, $F(1,11) = 9.318$, $p < .05$. Again, students with weaker math skills were more likely than students with better math skills to listen to hints. However, there was no relationship between the activation of hints and math proficiency for the four most difficult problems, perhaps because the students knew that they could skip the problems that they thought were too difficult. For example, David did not listen to any hints on the hard problems because he decided to skip these problems, saying that they were too difficult.

Feedback about the features of AnimalWatch-VI-Beta

Both during and after the sessions, the students provided a wealth of information about their experiences using the system and how they believed the system could be improved for future users who have low vision or are blind.

Clarity of speech and ease of access

Of the 14 participants, 13 stated that the program's speech was easy to understand, although 5 participants identified specific words or phrases that needed to be stated more clearly. Six participants thought that the current rate of speech was adequate, but 9 recommended that users be able to adjust the speed at which the speech was played, and 4 would like to have had different voices to choose from. Four participants commented on the ease of moving through the problems in the program, and 2 thought that the use of the space bar to advance through problems was a good feature. When they initially used the program, 4 participants recommended that the program periodically remind the user to press the space bar. Similarly, 2 participants suggested that users be reminded of the availability of hints. Five participants recommended that users be able to control movement within each problem so as to access a problem a word or sentence at a time.

Tutorial

Six participants thought that the initial tutorial about the key commands used for navigating the system was helpful. Five participants recommended that the tutorial review all shortcut keys, and 10 participants stated the importance of using consistent language between the tutorial and the problems. This latter comment was based on the way fractions are entered into the program. To enter the fraction ½, participants type 1, slash, 2. In the tutorial, the word "slash" is used, and in the problems "over" is used.

Current features

As they worked with the program, the participants commented about the features. Nine of the 14 participants liked that as the backspace was pressed, they were told what was being deleted ("deleted 42," for example). Three participants thought that pressing the "c" to clear a wrong answer was a good feature, but 3 others thought that this was not a necessary feature. Similarly, 7 participants liked having to press "g" twice to verify that they wanted to give up and move onto the next problem, but 4 thought that it was necessary to press "g" only one time. Two participants liked that "oops" was said when a wrong key was pressed, but 3 thought that the name of the key that was pressed should be said. Three participants liked that the program verified the correct answer. Other suggestions made by individual participants were that after pressing "q" to quiet the speech during the reading of a problem, "s" should be pressed to start the speech back up and that "a" should be pressed to toggle through the hints, rather than "a" for the first hint and "b" for the second hint.

Future features

The 14 participants had many recommendations for features that could be added to enhance future versions of the software.

These suggestions included allowing teachers to put in their own feedback for students ($n = 3$), making the interface more "gamelike" ($n = 2$), pressing "d" to hear a description of the animal the problem is about ($n = 2$), having a way to hear a description of a graphic by moving through it using the keyboard's arrow keys ($n = 2$), and allowing users with low vision to set up the desktop environment so they can see the screen efficiently ($n = 2$).

The participants provided the research team with additional recommendations that were not specifically tied to this version of the computer program. These recommendations included preparing a graphic of the animal in the problem and sharing it with an audio description ($n = 2$); adding more problem sets on other science topics, such as space, plants, or physics ($n = 6$); developing problems about nonscience topics, such as sports or computer programming ($n = 6$); and providing the text of the problems in braille in addition to an audio format ($n = 5$).

Discussion

This article has reported on a pilot study that was conducted with 14 students with visual impairments in Arizona. The participants used a computer program called AnimalWatch-VI-Beta to complete prealgebra math problems. Data were gathered about the use of audio hints to guide students to solve the problems accurately. In addition, the participants provided feedback about the current features of AnimalWatch-VI-Beta and recommendations for how the program could be improved and expanded to make it more accessible to students with visual impairments.

The incorrect answer rate might have been slightly higher for the easy problems because these items came first in the sequence of problems; some of the errors made on the easy problems might have occurred because the students were using a relatively unfamiliar interface. In addition, the students were more likely to skip the hard problems than to attempt to answer them.

There were several limitations to this project. First, minimal data were collected about the participants and how they access mathematical work in their educational settings. Hearing a problem on a computer and reading it in one's preferred medium (print or braille) are not the same skill, so it is possible that the performance of some students on the math computation was not representative of their typical work. Second, data were collected during one session, so it is possible that some students were nervous about the project and about working with researchers who were unfamiliar to them and, thus, may not have performed to their full potential.

Third, because one of the primary goals of the study was to gather data about the usefulness of the current features of the program and recommendations for future features, there were times when the researchers asked questions that might have interfered with the participants' math-solving processes. Fourth, some of the word problems might not have provided enough descriptive information for the students. For example, several problems in the unit about the right whale referred to scientists who use small planes to track whales in the Atlantic Ocean, which may have been difficult for students with limited visual background knowledge to imagine. Finally, the measure of math proficiency that was used in the study was limited (teachers' or parents' reports). Thus, the reported relationship between math proficiency and students' use of hints needs to be replicated, as does validation with more direct measures of students' math performance.

Although the study was not designed to provide a direct test of students' math problem-solving proficiency, some aspects of the problem-solving data provide insights into the potential value of audio features in technology-based learning environments. The students were able to solve most of the easy and medium-difficulty problems correctly and used many of the integrated audio hints as they worked on the problems. The hints appeared to be especially helpful for students who were working below grade level in math, according to their teachers of students with visual impairments or parents. The results are consistent with other recent studies that suggested that audio materials can be useful resources for students with visual impairments in learning math (Champion, 1976–1977; Ferrell, Buettel, Sebald, & Pearson, 2006; Hansen, Shute, & Landau, 2010; Landau, Russell, Gourgey, Erin, & Cowan, 2003; Mangold, 2003; Miele & Van Schaack, 2009).

In the short time that the participants worked with AnimalWatch-VI-Beta, they identified features that were helpful to them and made recommendations for additional features that they would like future versions of the program to contain. It was clear from the feedback that they provided and the anecdotal observations that the research team made that different users approached the interface in different ways. Therefore, it is imperative that users be able to customize the program to meet their own learning needs.

For this pilot study, only 12 of the 800 problems in the AnimalWatch tutoring system were used. The research team is seeking funding to develop the AnimalWatch-VI Suite, which will provide a more robust tool for students to develop their prealgebra skills. This suite will contain all 800 problems with audio narration, books in print or braille containing the text of the word problems, and accessible graphics (large print or braille) with audio narration. Users would be able to listen to descriptions of the animals to provide background information that may not have been accessible to students with visual impairments. Users will be able to customize the computer environment according to their visual needs (such as the font size or background color) and to have audio play on demand or automatically. The data gathered from this pilot study will be instrumental in assisting the research team to develop this suite.

Children with visual impairments need to have access to the same curricular materials as their sighted peers. If they must spend time and cognitive resources working hard simply to access instructional material, then those resources are not available to help them develop critical math skills. As Presley and D'Andrea (2008, pp. 12–13) noted:

> When students have the right tools to improve their efficiency, not only do they have a better chance for additional educational opportunities, but more time becomes available to them to develop skills that will be valuable beyond school and that can be used as the student makes the

transition into higher education, vocational training, and the world of work and independence.

With further development and research, the concept of an AnimalWatch Suite, based on AnimalWatch-VI-Beta, has the potential to increase the math skills of youths with visual impairments.

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