Applying Behavioral Strategies for Student Engagement Using a Robotic Educational Agent

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***Abstract*—Adaptive learning is an educational method that utilizes computers as an interactive teaching device. Intelligent tutoring systems, or educational agents, use adaptive learning techniques to adapt to each student's needs and learning styles in order to individualize learning. Effective educational agents should accomplish two essential goals during the learning process – 1) monitor engagement of the student during the interaction and 2) apply behavioral strategies to maintain the student's attention when engagement decreases. This paper focuses on the second objective of reengaging students using various behavioral strategies through the utilization of a robotic educational agent. Details are provided on the overall system approach and the forms of verbal and nonverbal cues used by the robotic agent. Results derived from 24 students engaging with the robot during a computer-based math test show that, while various forms of behavioral strategies increase test performance, combinations of verbal cues result in a slightly better outcome.**

***Index Terms*—social robotics, educational agents, engagement**

I. Introduction

In successful classroom settings, teachers are able to observe a students engagement in real-time and employ strategies to reengage the student, which, in effect, improves attention, involvement and motivation to learn [1]. This is also true during one-on-one tutoring sessions due to the fact that tutors are able to track engagement in real-time and respond appropriately. In general, teachers are able to engage by implementing behavioral cues such as direction of attention, posture, facial expressions, proximity, and responsiveness to instructional activity [2]. This behavioral engagement is a crucial component in education because it is often related to the academic achievement of a student [3], [4].

Currently, computer-based education (CBE) is a widely used method of instruction inside the classroom and at home. Research has shown that CBE actually improves academic achievement [5] and student motivation [6] when compared to traditional classroom instruction. Using CBE reduces the amount of instructional time required and increases the student's attitude towards learning [7]. Although research has shown CBE as being a highly effective learning tool, it pales in comparison to a human tutor [5]. Therefore, it has been stressed that CBE should be used as a supplement to traditional instruction rather than as a replacement [8].

To fill the gap between CBE and human tutors, it has been theorized that robotic-based education (RBE) can approach the effectiveness of human tutors by coupling methods in computer-based education with human-equivalent behavioral cues of engagement. In efforts to analyze the RBE approach, research has been conducted on both implementing sociable [9]–[14] and educational robots [9], [11], [12], [14]–[17]. Interaction between the student and teacher is best modeled as being a social dialog; therefore, tutoring is considered to be a task example for socially assistive robots [9]. Sociable robots are not only being used in education, but also as weight-loss coaches [10], play partners [14], and companions [10], [14]. By using a sociable robot, a long-term relationship between the robot and the subject is fostered [10]. This relationship drastically increases the subjects motivation to complete a task and the subjects desire to spend time with the robot for a long period of time. These two characteristics are ideal for a student in a learning environment.

In the realm of education, robots are currently being used to teach math [17], history [12], new languages [9], [16], and even new tasks [11], [14]. Some studies vary the type of feedback (positive, negative, neutral) [12] and behavioral techniques [1] given from the robot, while others vary the type of learning adaptation [17] provided from the system. Generally speaking, students are more attracted to the robot when it exhibits positive feedback [9], [12], are more motivated to learn from the robot when there is individualized learning [11], [17], and have increased recall abilities when the robot uses appropriate behavioral techniques to reengage [1].

As such, in this paper, we detail a system that integrates a robotic educational agent into a math learning scenario and discuss the processes employed to reengage the student using behaviors comparable to that of a human teacher. We want to test the hypothesis that a robotic educational agent that

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can adaptively engage the student during the learning process can positively impact their performance. Section 2 provides an overview of the learning environment whereas Section 3 discusses the robotic educational agent and its attributes. In Section 4, we discuss the engagement model used to identify user state and the associated robotic behaviors used to engage the student. The experimental protocol used to evaluate the effectiveness of the robotic agent is presented in Section 5. Finally, results and discussion points are made in Sections 6 and 7.

II. The Learning Environment

In traditional learning scenarios, active engagement is an important goal for both students and teachers [18]. One of the most non-engaging, yet necessary, elements of the current learning environment is the process of testing [19]. As such, in this research, we focus on the math testing scenario to evaluate the role and effectiveness of engagement using a robotic agent. For our work, we employed a 15-question multiple-choice calculus test, which was proctored using a Samsung Galaxy Tablet (Fig. 1). There were three distinct display screen layouts throughout the test: the welcome screen, the multiple-choice test screen(s), and the completion screen. The first screen, the welcome screen, introduces the student to the system and enables initiation of the test. The test, itself, is composed of a sequential set of screens that highlights a single question, with an associated image when applicable, and a set of multiple-choice answers with button choices A, B, C, and D (Fig. 1). The application only allows the subject to make one selection, and then he/she will press the Next button located at the bottom of the screen to move forward to the next test screen. The application does not allow students to navigate backwards during the test. Once the subject reaches the last test screen, a Submit Test button replaces the Next button. Once pressed, the completion screen is displayed, and the test has been completed.

III. The Robotic Educational Agent

For the robotic educational agent, we utilized the DARwIn-OP platform (Darwin) [20], a humanoid robot with 20 actuators, resulting in 6 DOF for each leg, 3 DOF of freedom for each arm, and 2 DOF for the neck (Fig. 2). To enable

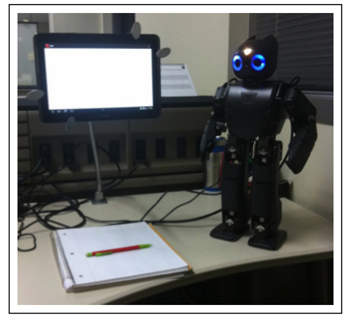


Fig. 2. The Robotic Educational Agent Darwin.

interaction with the human, Darwin was programmed with a range of verbal and nonverbal behaviors.

A. Nonverbal Behaviors

Nonverbal behaviors, or gestures, for the robotic agent included eye gaze, head nods/shakes, and body movements. These were programmed using Darwins default program ActionEditor in which we programmed a sequential set of actuator positions, with speed and timing constraints, to affect an appropriate gesture. Table I shows a sample of the nonverbal behaviors used in this investigation, and Fig. 3 shows snapshots of the *fast arm* gesture.

B. Verbal Behaviors

Verbal behaviors enable the educational agent to provide socially supportive phrases for reengagement as the student navigates through the test. During the utterance of verbal phrases, Darwin turns his gaze towards the student when speaking; otherwise, he remains looking at the tablet. The goal of the verbal phrases is to encourage the student based on their current performance on the test (i.e. answering a question correctly/incorrectly; speed of answer; taking too long to answer). It is very important that the phrases are socially supportive and convey the message that the subject and Darwin are taking the test together as a team. There is a dialogue established between the subject and Darwin, and not a unidirectional knowledge flow (i.e. Darwin is not giving instructions or issuing commands to the subject). This open dialogue integrating socially supportive phrases between

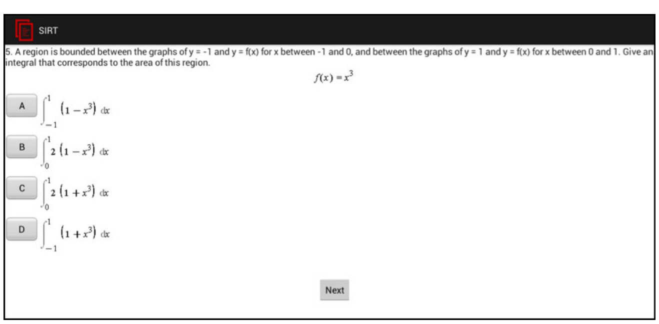
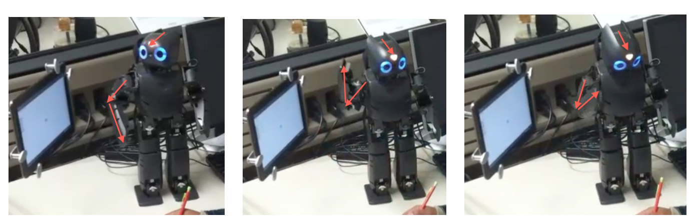


Fig. 1. The Learning Environment - Calculus Test Question Screen.



(a) (b) (c)

Fig. 3. The fast arm gesture broken down into three parts. (a) Initial Position - Darwin is standing and has eye contact with the tablet-based test. (b) Darwin's right arm is raised, and eye contact is towards the student. (c) Darwin's arm is brought down at a fast speed, and his head follows this downward motion. He then returns to the initial position.

TABLE I
SAMPLE OF NONVERBAL BEHAVIORS FROM THE ROBOTIC EDUCATIONAL AGENT

Gesture	Behavioral Meaning	Description of Motion
Conversation	Body movements used to engage people while talking	Head nods and both arms move outward while maintaining eye contact
Head Nod	Back-channel signal meaning continue; okay; yes	Head moves in an up and down motion
Head Shake	Negative connotation; sad; no	Head moves from side to side while facing the ground
Tri-gaze	Eye contact distributed between three different things	Eye contact with the tablet, student, then workstation for 3 seconds each
Head Scratch	Confusion; lost	Arm/hand moves back and forth next to head
Fast Arm (Fig. 3)	Positive connotation; approval; excitement	Arm is bent and raised next to head; arm then quickly moves downward

teacher and student is ideal for optimal learning [9]. A sample of these socially supportive phrases is shown in Table II. For implementation purposes, the phrases were recorded using text-to-speech (TTS) software and stored on Darwin's external SD card as mp3 files.

IV. THE ENGAGEMENT MODEL

Computer-Based Education (CBE) only focuses on comprehension of material [21] and not real-time engagement/reengagement, which is essential for optimal academic achievement. Comprehension is determined solely by the validity of answer selections. However, for a system to be optimum, it must properly reengage the student when they become off-task. Computer-based tools only focus on comprehension because of the difficulty associated with determining cognitive states. However, by monitoring user state, we propose that we can also monitor engagement. In this work, we determine the behavioral user state by monitoring the student's interactions with the tablet. For a baseline metric of engagement, three event processes were observed: total time required to answer a question; accuracy of responses; and proper function executions. By looking at variables such as the speed and the validity of the answer submitted, assumptions are made about the users state of mind (Table III). This information also assists with the development of appropriate socially supportive responses for Darwin. For example, if the student responds to a series of questions at a fast pace, but the majority of the answers are incorrect, the student may be disengaged, bored with the problem set, or need questions of less difficulty.

TABLE II
SAMPLE OF VERBAL RESPONSES FROM THE ROBOTIC EDUCATIONAL AGENT

Answer	Speed	Phrase
Correct	Fast	"You really know your stuff!
		"You're a genius!
		"Fantastic!
	Slow	"This is hard, but we're doing great."
		"Thanks for all your hard work."
		"This is really making me think."
Incorrect	Fast	"Wait, I didn't get to read that one."
		"Hang in there. We're almost done."
		"Im lost. You're going to fast."
	Slow	"Don't worry. I had trouble with that one to."
		"That one was very challenging."
		"Don't sweat it, we'll get the next one."
None	Inactive	'Let's make an educated guess."
		"I was completely stumped on this one."
		"Don't forget about me over here."

V. EXPERIMENTAL DESIGN

To evaluate the effectiveness of the robotic educational agent to engage students during the learning process, we employed a between-groups design for this study. A total of 24 student participants took part in this experiment consisting of both females and males in the age range of 18-33. Our experiment involved one factor, type of reengagement, with four levels. Each level is defined as follows:

- **None:** Represents the control group. No agent is present.
- **Verbal:** The agent will say socially supportive phrases for reengagement as the student navigates through the test. He will gaze towards the student when speaking to him/her; otherwise, he will remain looking at the tablet.
- **Nonverbal:** The agent will use only gestures for reengagement as the student navigates through the test.
- **Mixture of Both:** The agent will use both gestures and phrases for reengagement as the student navigates through the test.

The experimental scenario (Fig. 2) utilizes a Samsung galaxy tablet to display the exam. The tablet is placed on an adjustable stand at eye level and Darwin is positioned to the right of the tablet, yet between the tablet and the student. Darwin is conveniently placed in a position where he is always able to see and interact with both the tablet and the student.

At the start of the application and/or welcome screen, Darwin gives a verbal introduction along with gestures to introduce himself and the activity that the students are about to perform. The purpose of this introduction is an attempt to eliminate the novelty of the robot from the investigation, and prepare the students for the test by instructing them to gather their materials. The script of this verbal introduction is shown below:

TABLE III
ENGAGEMENT MODEL

Answer	Speed	User's Behavioral State
Correct	Fast	Engaged
		Not challenged enough
	Slow	Engaged
		Challenged
		Requires more time to think
Incorrect	Fast	Not engaged
		Unmotivated
		Not challenged (too hard/easy)
		Bored
	Slow	Engaged
		Challenged
		Struggling

"Hello my name is Darwin. We will be going through a series of 15 math questions to learn the material together. I appreciate you taking the time out of your busy schedule to work with me. Get your pencil and paper ready so we can start. Press begin when you're ready."

The subjects will then navigate through the test until they reach the completion screen. Thereafter, Darwin shows his gratitude and gives a farewell.

As each student progresses through the test, their interactions with the tablet is communicated to Darwin via Bluetooth. To enable real-time performance, only the numbers 0-9 are transmitted from the tablet to the Darwin. Each number conveys a different message to Darwin about the interaction between the student and the tablet. Basically, every button that is pressed is sent to Darwin, as well as the time intervals taken to navigate through the test. Table IV defines what each number represents to Darwin.

Upon opening the tablet-based math test, 0 is sent to Darwin and he then begins his introduction on the welcome screen. If a multiple-choice answer is selected (A, B, C, or D), a 1 is sent to Darwin and he will respond appropriately based on the engagement type (verbal, nonverbal, or both). An answer is classified as either being *fast*, *slow*, or *average* based on the time elapsed on each question: if the subject submits a response in less than 30 seconds this is fast; if the subject submits a response in between 30 and 90 seconds this is average; if the subject submits a response in more than 90 seconds this is slow. (The threshold for the time intervals are based on the results from pilot testing.) The answers are also classified based on whether or not the answer is correct. Messages 2-7 are the numbers sent to Darwin based on the answers submitted on the tablet.

To improve human-robot team performance, Shah et al. was able to reduce a subject's idle time by monitoring the beginning and end of tasks [22]. Based on the results from this study, we focused on decreasing idle time by monitoring task or question duration. Therefore, when there are long time intervals where there is no interaction between the human and the tablet, 8 is sent to Darwin. A long time interval is defined as 90 seconds; therefore, every 90 seconds of inactivity or idle time, Darwin is notified and he will respond appropriately based on the engagement type. Lastly, 9 is sent to Darwin at the completion of the test.

TABLE IV
BLUETOOTH COMMUNICATION PROTOCOL BETWEEN THE TABLET AND DARWIN

Message Sent from Tablet	Time (s)[a]	Button Pressed on Tablet	Answer
0	n/a	Start App Icon	n/a
1	n/a	A, B, C, or D	n/a
2	$t<30$	Next	Correct
3	$t>90$	Next	Correct
4	$30<t<90$	Next	Correct
5	$t<30$	Next	Incorrect
6	$t>90$	Next	Incorrect
7	$30<t<90$	Next	Incorrect
8	$t^b=90n$, $n>0$	n/a	n/a
9	n/a	Submit Test	n/a

[a] The time, t, resets at the start of each question.
[b] The time, t, resets after each interaction with the tablet.

Depending on user state, Darwin provides the users cues that are either verbal, nonverbal, or a combination of the two (depending on the experimental group). For both verbal and nonverbal behaviors, the behavior was selected at random based on the message sent to Darwin from the tablet. For the engagement type that incorporates both verbal and nonverbal cues, the gestures and phrases were scripted and paired prior to Darwin's random selection. As such, we were able to expand Darwin's library of verbal and nonverbal cues by pairing the same phrase with multiple gestures. Although a phrase when it stands alone may mean one thing, by adding a gesture, the underline meaning of the message can be altered. Upon execution of a pair, both the gesture and the phrase are performed simultaneously. For example, if 3 (Slow correct answer submitted) is sent to Darwin, he may say, "This is hard, but we're doing great," while nodding his head.

For the experimental design, we utilize the same test, environmental setup, and engagement model across all students (so that cues will happen at the same time). The only thing that changes between groups is the type of cues that Darwin provides.

VI. RESULTS

In this research, we look to validate the hypothesis that the use of a robotic educational agent can increase test performance by adaptively engaging with the student. Adaptive engagement is based on the concept that the engagement model is driven by identification of the behavioral state of the student. To prove or disprove this hypothesis, we will look at the different kinds of information that we collected separately. These include test completion time, the Likert scale questions that we asked in an exit survey, and the comments that participants left at the end of the survey.

A. The Completion Time

We logged the total test time for each participant, and the means for the four groups are shown in Fig. 4, and the statistical analysis is shown in Table V.

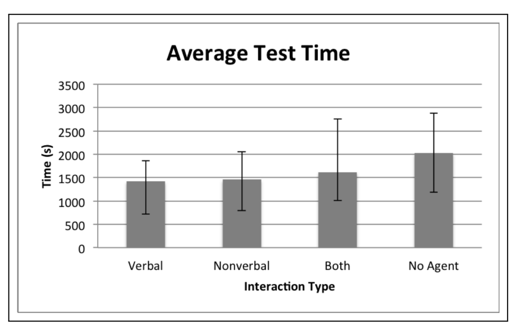


Fig. 4. The average test completion times shown along with the range for each group.

TABLE V
TOTAL TIME (S) STATISTICAL ANALYSIS

	Mean	Standard Deviation	p-value
Verbal	1,424.50	405.70	0.28
Nonverbal	1,461.83	533.33	
Both	1,618.33	673.84	
No Agent	2,026.83	673.90	

B. Survey

After each subject completed the test, we asked them to rate their agreement with a series of statements on a 5-level Likert scale that ranged from 1 (Disagree) to 5 (Agree). One question asked for a 'yes/no/maybe' answer, which we converted to a scale from 1 (No) to 3 (Yes). For each of the questions on our survey, we performed an ANOVA (Analysis of Variance) test to see if the differences between groups were significantly different. Table VI shows the average response to each question and the p-values from the ANOVA tests, which are separated by test groups.

C. Freeform Feedback

In addition to the questions discussed in the previous subsection, we also left room on the survey for subjects to provide freeform comments that reflected their experience as a whole. Though not everybody decided to accept the invitation, 12 of the 18 participants provided comments. An interesting trend was the observation that many participants (50%) commented that they felt rushed by Darwin. Some participants described him as impatient, annoying, and nerve wracking. Yet, on the quantitative survey results, participants slightly disagreed with the statement that Darwin distracted them during the test (Slightly Disagree = 2; Avg = 2.4; Stdv = 1.3). Many of the participants also claimed to have been worried about their performance and of letting Darwin down by performing poorly on the test (25%). These statements are corroborated by the quantitative survey results that show slight agreement with the statement "I was afraid of letting Darwin down" (Slightly Agree = 4; Avg = 3.9; Stdv = 1.2). Many of the subjects also claimed to have found Darwin interesting, describing him as cute and friendly (25%). These comments are reflective of a slight agreement among participants that they liked Darwin (Slightly Agree = 4; Avg = 4.4; Stdv = 0.9). This range of responses to Darwin's personality could indicate a few things. First off, it seems that Darwin's presence was a helping factor in situations where participants were worried about disappointing Darwin. However, a balance needs to be found between an annoying versus an encouraging personality. At this stage, it seems that there is more work to be done before all users relate to Darwin as an encouraging tutor.

VII. DISCUSSION

At first glance, the amount of time spent on the test decreases when Darwin is present. On average, the test took 1497 seconds when Darwin was present, but took approximately 2027 seconds without Darwin. By monitoring and acknowledging the beginning and end of tasks, Darwin was able to effectively decrease idle time and maintain the subject's attention. The verbal group was able to perform this objective best with an average test time of 1425 seconds, and the nonverbal group followed with 1462 seconds. The verbal group also presented a standard deviation of 406 seconds, which was the smallest when compared to the remaining groups (Table V).

There was a significant variance in how nervous the subjects deemed themselves to be during the test with and without Darwin. The group without Darwin (No Agent) was the least nervous during the test with a score of 1.00 (Disagree = 1; Stdv = 0), while the remaining groups with Darwin had an average score of 2.72 (Neutral = 3; Stdv = 1.4). This may be attributed to the subjects' fear of letting Darwin down during the test (Slightly Agree = 4; Avg = 3.9; Stdv = 1.2). This fear in effect makes the subjects nervous, which is only natural. In addition, the fact that the subjects have fear of disappointing Darwin proves that a personal relationship was built between Darwin and the human on some level.

In regards to education, avoiding boredom is critical being that it is often associated with poorer learning and behavior problems [23]. While most participants agreed that the test was difficult, with an overall average score of 4.29 on that survey question (Slightly Agree = 4; Stdv = 0.9), the average response to the question on boredom during the test was 2.16 (Slightly Disagree = 2; Stdv = 1.2). This implies that, though the test was difficult, the participants did not feel bored. This could be an important insight in improving our engagement model – taking a test that is not easy is not necessarily going to cause students to lose interest. If we delve deeper into this, the interaction type with a mixture of verbal and nonverbal cues shows a trend to have the least amount of boredom with an average score of 1.50 (Slightly Disagree = 2; Stdv = 0.5). This may be because Darwin is able to communicate more clearly with the student, but more research needs to be conducted to further validate this observation.

VIII. CONCLUSION

Across all interaction types, verbal, nonverbal, and both, the subjects enjoyed Darwin and were not distracted by his presence during the test. They were able to build a relationship with Darwin and did not wish to disappoint him with their performance. When compared to having no educational agent present, every interaction type that Darwin implemented was successfully able to maximize the time used in the learning environment. This was achieved by using the engagement model to monitor progression through the test and effectively eliminate idle time. In particular, the verbal engagement implemented on Darwin was able to reach this goal best, although by a small margin. Lastly, a mixture of verbal and nonverbal cues tends to have the least amount of boredom associated with it, which is ideal for a richer learning environment. Overall, the use of only nonverbal cues such as gestures shows no significant trends when compared to verbal cues; therefore, this

TABLE VI
STATISTICAL ANALYSIS OF SURVEY RESPONSES

Topic	Question	Verbal	Nonverbal	Both	No Agent	p-value
Test	I found this test difficult	4.00	4.67	4.67	3.83	0.25
	I performed better on this test than I had anticipated	3.00	2.67	3.33	3.17	0.74
	I was nervous during this test	2.50	3.33	2.33	1.00	0.03*
	I finished this test quickly	3.00	1.50	2.67	2.67	0.08
	I was frequently bored during this test	2.00	2.83	1.50	2.33	0.25
	This test was an appropriate level for my skills	3.33	2.50	3.00	4.33	0.13
	I enjoyed taking this test	3.00	2.83	3.33	4.17	0.31
Darwin	I performed better on the test with Darwin than I would have alone	3.33	2.00	3.00	n/a	0.14
	Darwin distracted me during the test	2.17	2.50	2.50	n/a	0.90
	I was comfortable with Darwins presence	3.50	3.33	4.33	n/a	0.27
	Darwin made me work more quickly than usual	3.50	2.83	3.83	n/a	0.25
	Darwins feedback was helpful	3.33	3.00	3.50	n/a	0.74
	I was afraid of letting Darwin down	3.50	4.50	3.67	n/a	0.31
	Darwin always reacted appropriately during the test	3.50	2.33	3.33	n/a	0.17
	Darwin made me less nervous during the test	2.83	2.33	2.83	n/a	0.57
	Darwin helped me to stay focused on the test	3.33	3.67	3.17	n/a	0.69
	I like Darwin	4.17	4.50	4.67	n/a	0.62
	Are you interested in taking Darwin to a real test	2.17	2.17	2.00	n/a	0.92

* Statistically significant.

works suggests that verbal engagement is ideal for enhancing test performance in RBE.

IX. FUTURE WORK

We would like to expand this research to use children as subjects rather than college-aged individuals and older. It could very well be possible that younger children have different priorities, and so prefer a particular communication mode to another. The framework from this test could easily be reused for such an investigation, though the calculus questions will have to be replaced with grade-level appropriate curriculum.

The other key direction in which we would like to build on these results is in implementing a proper robotic tutor that employs machine-learning techniques to build a model of the student with whom it is interacting. Even in our current setup, where everything was essentially scripted based on a few simple cues, many participants attributed far more intelligence to the Darwin robot than it was due. For example, one subject repeatedly asked Darwin what he thought on each question and ran his answers by him before submitting them. Though this 'pretending' behavior could be useful in itself in a therapeutic kind of way, a robot that can truly understand and respond to such cues should be a more valuable asset to the child who benefits from its tutelage.

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