Web-Based Problem-Solving Environment for Line Balancing Automated Manufacturing Systems

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Abstract

This paper describes a web-based problem-solving environment designed to teach line balancing of automated manufacturing systems. This environment was designed based on analytic and simulation models of an assembly line. Simulation models were first designed and used to derive data about work-in-process amounts, workstation utilization, cycle times and amount of finished product under different parameter settings, such as processing time and arrival rate. Regression models were then designed to mimic these results. The data from these models were then used as a basis for designing Flash animations. The line balancing problem-solving environment allows students to make adjustments to a simulated production line, and to run the simulation to view the results. The environment was evaluated by 28 undergraduate students enrolled in a production systems course and by 39 students who had completed a production systems course within the past two years. Students completed a pre-test before using the environment and a post-test afterwards. Differences between students' pre- and post-test scores were significant ($\alpha = .05$). Future directions include using the environment for research on system integration skill development, field testing with engineers from industry, and design of a "construction set" for robotic work-cell line balancing.

1. Background

Simulation games have become increasingly popular in training and education in recent years. Forssen and Haho[1] present an overview of social simulation game methods in training and participative development. They noted that these methods enable individual learning and promote both single-loop and double-loop types of organizational learning. In engineering education, simulation games have been used in teaching the software engineering development process[2], electromagnetic education[3,4], digital logic[5], concurrent engineering for product/process development[6], supply chain management in automobile manufacturing[7], electronic/circuit card design, assembly, fabrication, and distribution [8,9,10], and general manufacturing planning and quality management activities[11,12]. One particularly interesting simulation game is a virtual disk drive design studio described by Richkus et al.[13] Students must design and launch new disk drives within a certain time frame, simulating the idea of time-to-market. Students can build on three different kinds of learning styles: (1) literature search and abstract theory; (2) consultations with experts; and (3) design studio.

The first author recently received an NSF grant to investigate how engineers develop automated manufacturing system integration skills. In the course of interviewing engineers from automated system design companies, we learned that line balancing automated systems in the final stage before installation is a particularly difficult and critical task. Theoretical work on line balancing has been developed since 1980, but as manufacturing technology has advanced, the complexity of the problem has increased as well.

There has been little work in development of simulation games for teaching line balancing. Mazziotti, Armstrong, and Powell designed a simulation-based Line Balancing Decision Trainer that provides lessons and practice sessions to help users improve line balancing skills[14]. However, little information was reported about the effectiveness of this system.

The objectives of this paper are: (1) to describe a prototype web-based problem solving environment for line balancing of automated assembly lines, and (2) to report results from an evaluation of the effectiveness of the prototype. The prototype allows learners to manipulate workstation processing time and observe results in terms of accumulation of work-in-process (WIP), cycle time, and workstation utilization.

2. Line Balancing Problem Solving Environment Design

The line balancing problem solving environment prototype is designed to teach line balancing problem solving and important concepts such as cycle time. This is achieved using a combination of a tutorial and an interactive problem solving environment that allows learners to generate and explore their own hypotheses about how line balancing should work.

- The tutorial presents basic concepts such as definitions (production line, cycle time, work-in-process), calculation of workstation utilization and balance delay, and heuristics for allocating work contents to workstations given a desired cycle time. Numerous examples are provided and practice exercises are used to help clarify common misconceptions.

- A cycle time simulation game is used to allow users to practice line balancing. The game has two modes: interactive and simulation modes. In the *interactive mode*, users are prompted with a series of questions designed to address common misconceptions about line-balancing. The questions lead learners through the line-balancing problem-solving process in a structured manner, thus facilitating their development of a accurate mental model of the process. In the *simulation mode*, learners can actively adjust processing time (also called service time) conditions. Learners may either enter the simulation mode after completing the interactive mode, or they may opt to go directly to it (bypassing the interactive mode). Based on the learners' settings, the simulation shows how the assembly line flows, the amount of work-in-process accumulating in front of each workstation, the utilization of each workstation as time goes by, and the overall production line cycle time over the duration of the simulation.

To assure the fidelity of the simulations used within the simulation game, analytic and simulation models of an assembly line were created as part of the game design process. These models were used to derive data about work-in-process amounts, workstation utilization, cycle times and amount of finished product under different parameter settings, such as processing time and arrival rate. Regression models were then designed to mimic these results. The data from these models were then used as a basis for designing the simulation game.

Finally, the simulation game is also designed to collect data about user actions such as when learners click buttons and which buttons they click. This allows the simulation game to be used for research on users' problem-solving behaviors, as well as for teaching problem solving.

The prototype can be found at <http://etidweb.tamu.edu/hsieh/auto/LineB_cover.html>. Figure 1 is a screen shot of the home page. The *Line Balancing I*, *Line Balancing II*, and *Line Balancing Methods* links lead to tutorials. The *Cycle Time* link leads to the simulation game. Figure 2 shows a sample screen from the tutorial on methods of line balancing. This tutorial presents a heuristic method called the large candidate method by using an animated, step-by-step demonstration of the numerical process of assigning work elements to workstations.

Figure 3 shows the cycle time simulation game in its initial state. The boxes labeled Parts Feeder, Welding, Assembly, and Packaging represent four separate workstations on an assembly line. Learners may use the spin buttons located beneath each station to set the service time (i.e., processing time) at each workstation. They can then use the On/Off switch to start the simulation and the Pause or Forward buttons to freeze or restart the process while the simulation is running.

Figure 4 shows the cycle time simulation game midway through a run. The learner has changed the workstation service times from their initial (default) settings of 6, 6, 6, and 6 to 2, 2, 4, and 6 and turned the On/Off switch to On. Products (represented by colored boxes) are moving along the assembly line. Beneath the assembly line, the Utilization boxes show the percent of time that Welding, Assembly, and Packaging workstations are busy. Also, the Work-in-process bars show number of items (if any) between workstations that are waiting to be processed at any given time. Finally, the top right of the simulation shows the run length of the simulation and the cycle time for the assembly line in minutes.

Line Balancing
Problem Solving
Environment

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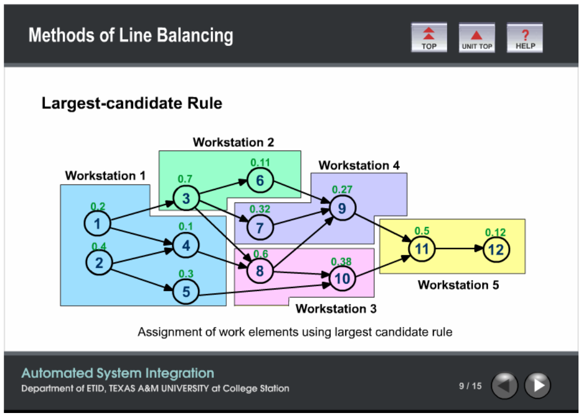
Figure 1. Line balancing problem solving environment – home page.



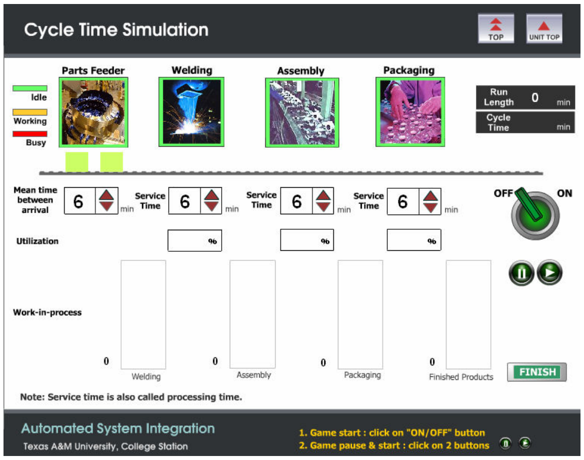
Methods of Line Balancing

Largest-candidate Rule

Assignment of work elements using largest candidate rule

Automated System Integration
Department of ETID, TEXAS A&M UNIVERSITY at College Station

Figure 2. Screen shot from tutorial on methods of line balancing.



Run Length 0 min
Cycle Time min

Mean time between arrival 6 min
Service Time 6 min
Service Time 6 min
Service Time 6 min

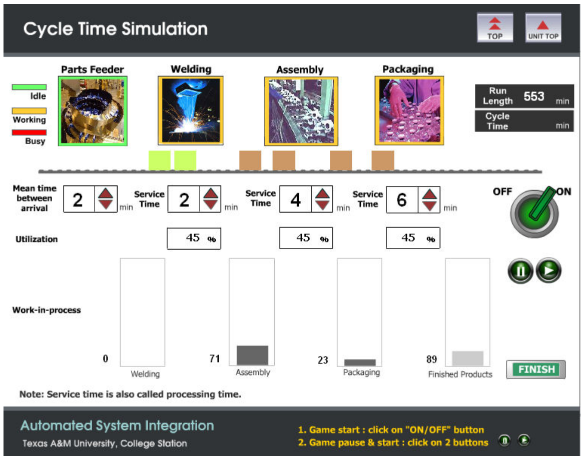
Utilization % % %

Work-in-process 0 0 0 0

Note: Service time is also called processing time.

1. Game start : click on "ON/OFF" button
2. Game pause & start : click on 2 buttons

Figure 3. Cycle time simulation game – initial state.



Run Length 553 min
Cycle Time min

Mean time between arrival 2 min
Service Time 2 min
Service Time 4 min
Service Time 6 min

Utilization 45 % 45 % 45 %

Work-in-process 0 71 23 89

Note: Service time is also called processing time.

1. Game start : click on "ON/OFF" button
2. Game pause & start : click on 2 buttons

Figure 4. Cycle time simulation game – midway through a run.

3. PROTOTYPE EVALUATION

The prototype line balancing problem solving environment was evaluated by undergraduate students to find out:

- Did the lessons help students to learn more about line balancing concepts such as cycle time, workstation utilization, and work-in-process?
- Student opinions about various aspects of the Toolkit, such as effectiveness, ease-of-use, and relevance to their education.
- Student comments.

In addition, a learning styles inventory was used to find out more about these students' learning styles in order to assess possible relationships between learning style and response to the prototype.

3.1 Participants, Materials, and Experimental Procedures

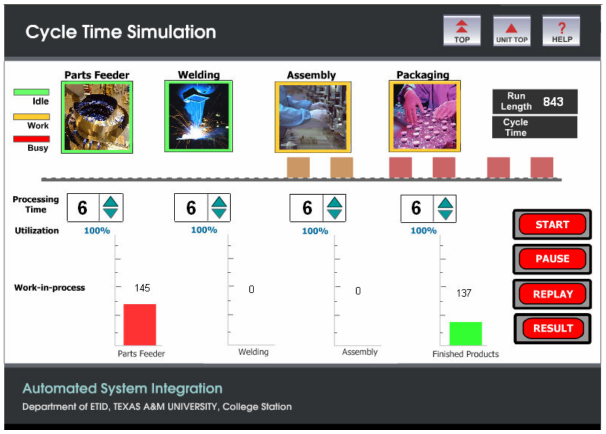
Participants. There were two groups of participants in this evaluation. The first group (Group I) consisted of 28 undergraduate students enrolled in a Production Systems course in which they were studying how to do line balancing of an automated assembly line. Evaluation activities took place during lab time. There were two labs of 14 students each.

The second group (Group II) consisted of 39 students who had taken the Production Systems course within the past two years and who were enrolled in a Manufacturing Automation and Robotics course at the time of the evaluation. Evaluation activities took place during lab time. There were two labs of 19-20 students each.

Materials. Evaluation instruments included two parallel 12-item multiple-choice tests and an opinion survey. This survey asked students to rate various characteristics of the prototype on a 7 point Likert scale. Figure 5 contains sample questions from the tests and opinion survey.

Felder and Soloman's Index of Learning Styles (ILS)[15] was administered to assess students' learning styles. The ILS is a 44-question survey that asks users about their learning preferences. The Index ranks users along four attribute continuums: Active/Reflective, Sensing/Intuitive, Visual/Verbal, and Sequential/Global. Each attribute pair (e.g., Active/Reflective) represents opposite ends of a 12-point scale. More information about the ILS can be found at http://www.ncsu.edu/felder-public/ILSpage.html

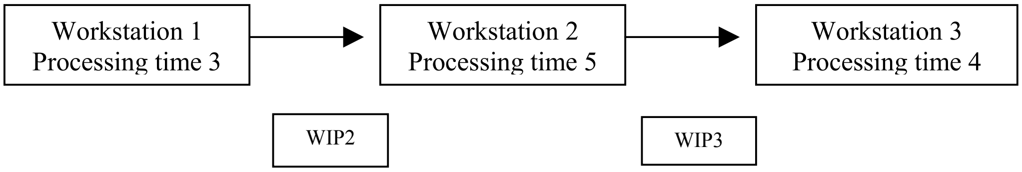
SAMPLE TEST QUESTION



In the top left of the figure, just above the assembly line, are two boxes—Run Length and Cycle Time. The Run Length box shows the number of minutes of assembly line operation that are being simulated. The Cycle Time box shows the number of minutes required for a single cycle (i.e., for one unit of a finished product to be produced). The red buttons on the right—Start, Pause, Replay, and Result—allow you to start and stop the simulation. Use Start to begin a simulation run, and Pause to pause a simulation midway.

Run the simulation as many times as you like. You should experiment with adjusting the processing time for each workstation until you feel that you understand the relationships between workstation processing times and the work-in-process (WIP) of each workstation, and between workstation processing times and overall cycle time.

Which a workstation has most work-in-process?



1) Workstation 2 (WIP2)
2) Workstation 3 (WIP3)
3) Workstation 1
4) None of the above

SAMPLE OPINION SURVEY QUESTION

I would like to have more courseware like this available to help me learn.

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

Figure 5. Sample test and opinion survey questions.

Procedure. We evaluated students' knowledge before and after using the prototype. Figure 6 shows the sequence of the evaluation activities.

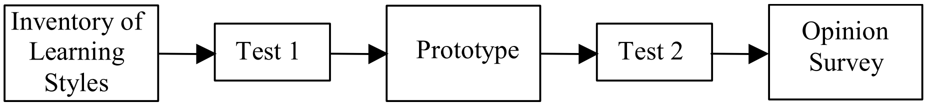


Figure 6. Evaluation event sequence.

3.2 Data Analysis and Results

This section summarizes results in terms of instructional effectiveness (as measured by the two tests), student attitudes (as measured by the opinion survey), and student comments. We also briefly review the relationship between the students' responses on the learning styles inventory and their responses to the opinion survey.

Test Data. We analyzed the test data to see if there was statistically significant score improvement among tests. Two stages of analysis were performed on the data sets. In Stage 1, the Shapiro-Wilks test was used to assess the normality of the data set. If a data set followed a normal distribution; then a t-test was used to do a paired data comparison in Stage 2. However, if a data set failed the normality test, then the Wilcoxon Ranks test was used for the paired data comparison in Stage 2. The null hypothesis H_o for stage I was that there is no difference between the distribution of the data set and a normal one. The null hypothesis H_o for Stage 2 was that there is no difference between two set of samples. Tables I and II summarize the test statistics, critical value and conclusions for each test, where the null hypothesis is $\mu_d = 0$ and the α value is 0.05.

The analysis results for the Group I subjects revealed that the data set failed the Shapiro-Wilks normality test. In other words, the data set was not normally distributed. Therefore, the Wilcoxon Ranks test was applied for the Stage II paired data comparison. The test statistic ($z=2.0409$) was rejected at critical value (1.96) at $\alpha = 0.05$. This implies the prototype caused significant improvement in learning.

The analysis results for the Group II subjects revealed that the data set was NOT rejected for Shapiro-Wilk normality test. In other words, the data set was normally distributed. Therefore, a t-test was applied for the Stage 2 paired data comparison. The test statistic ($z=3.8322$) was rejected at critical value (1.96) at $\alpha = 0.05$. This implies the prototype caused significant improvement in learning for this group as well.

Opinion Survey. We computed means for the opinion survey. Figure 7 summarizes these results. Student ratings were positive for all items. In general, students felt that the prototype was interactive, relevant, and easy to use and understand.

Student Comments. Student comments can be summarized as follows: 1) Many students liked the line balancing simulation; they felt being able to visualize the assembly line was very helpful. One even suggested adding video clips of actual assembly lines. 2) Some students suggested that providing more practice exercises would be helpful. 3) Overall, students thought the lessons were helpful, easy-to-use, and supplemented the lecture well.

Student Learning Style Survey. Figure 7 shows a summary of results for all four attributes from the Index of Learning Styles for the students in this study. These data suggest that many of these students had Active and Visual learning styles. Figure 8 shows results for the Visual/Verbal attribute, indicating that the majority of these students considered themselves to be primarily Visual learners with approximately half of the students on the extreme Visual side of the scale (9A and 11A). This finding is consistent with results from the opinion survey; for example, the mean response to the statement "The animations helped me visualize the process" was 5.5 out of 7.

Table I. Shapiro-Wilks test of normality for Groups I and II

	Test statistic	Critical value	Conclusion
Group I	Shapiro-Wilks W = 0.8999	0.95	Reject Null Hypothesis
Group II	Shapiro-Wilks W = 0.9623	0.95	Do not Reject Null Hypothesis

Table II. Paired comparison tests for Groups I and II

	Test statistic	Critical value	Conclusion
Wilcoxon Ranks test - Group I	z-score = 2.0904	1.96	Reject Null Hypothesis
t-test – Group II	z-score = 3.8322	1.96	Reject Null Hypothesis

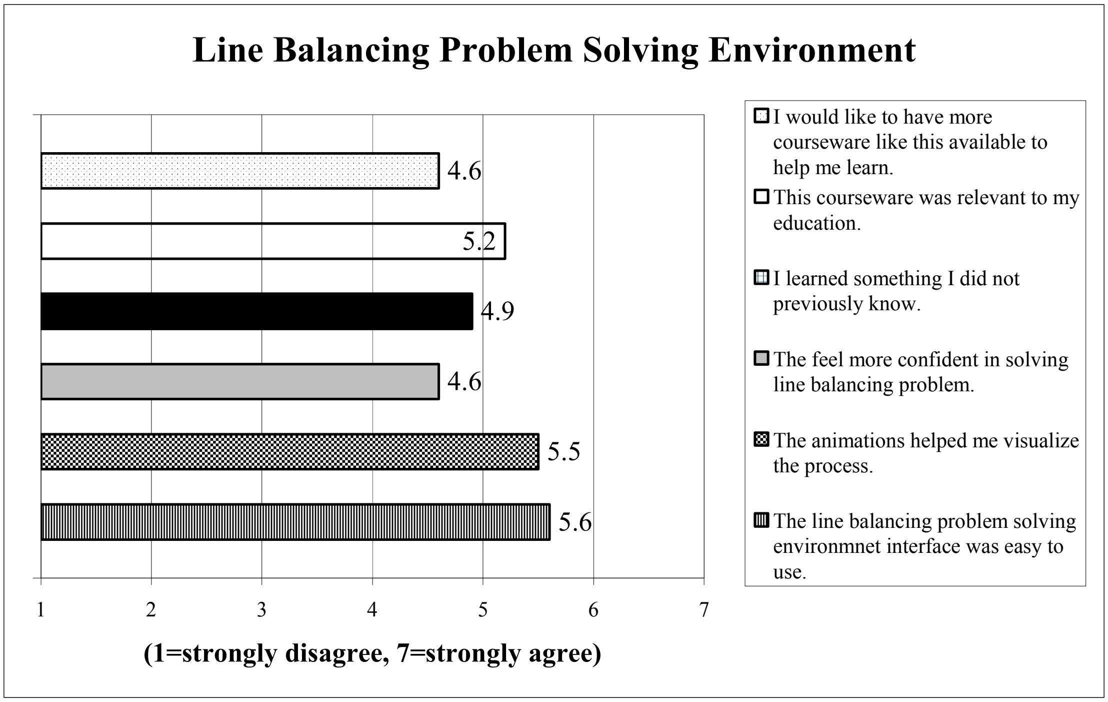


Figure 6. Summary of the Student Opinion Survey.

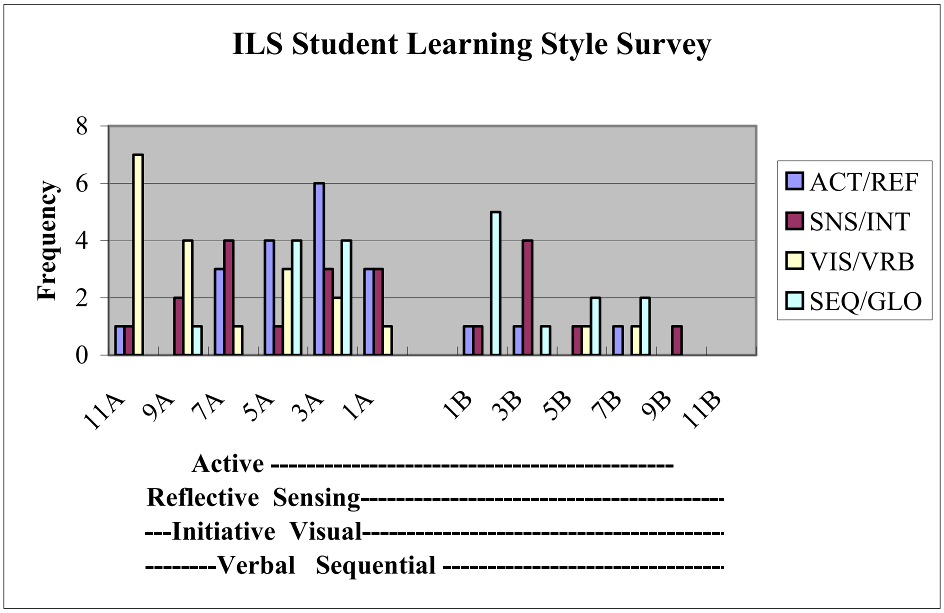


Figure 7. Summary of ILS Results for Four Attributes.

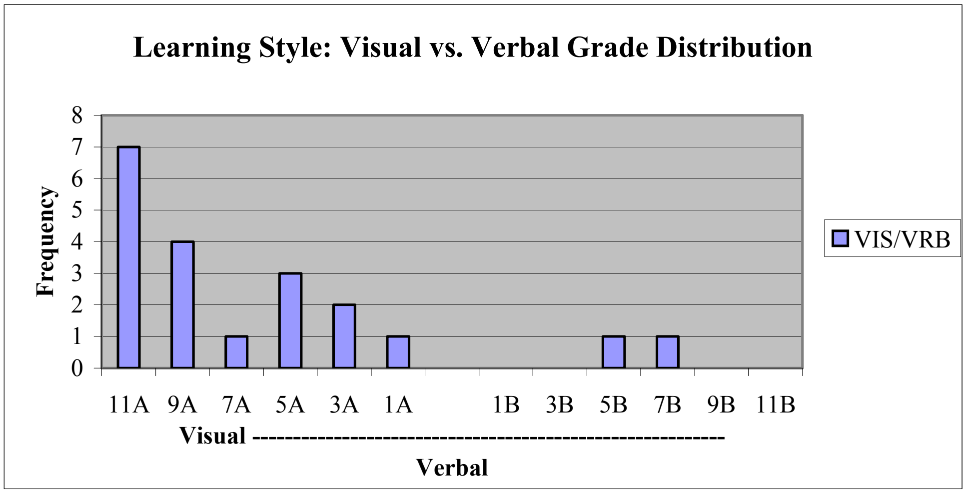


Figure 8. Summary of ILS results for Visual/Verbal attribute.

4. DISCUSSION

Based on these results, we may conclude that Line Balancing Problem Solving environment design is instructionally effective, and that students' subjective impressions of the system are positive. It appears that we may safely continue to develop and enhance similar types of lessons. Second, the simulation game was well-received, probably because it *helped students to visualize* relationships between bottleneck stations, work-in-process quantities, processing time (also called service time), station utilization, and cycle time. Continued use of this approach to illustrate other complex system integration concepts appears to be a good instructional strategy.

5. CONCLUSION AND FUTURE DIRECTIONS

We have briefly described continuing steps in the process of developing a system integration problem solving environment (SIPSE) for automated manufacturing system integration education. So far, our evaluation results have been very encouraging. We are currently in the process of developing more lessons. Future lessons will incorporate games and intelligent tutoring system for robotic work-cell/system design. Also, the problem scope will be extended from conceptual design to control logic design and mechanical system design. Ultimately we hope to have a complete system that can be used not only by undergraduate students, but also by high school students and industry professionals. Future directions include using the environment for research on system integration skill development, field testing with engineers from industry, and design of a "construction set" for robotic work-cell line balancing.

6. ACKNOWLEDGEMENTS

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