Integration of ICT and Unconventional Teaching Approaches into the Digital Systems Design Education towards its Efficiency Enhancement

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Abstract—**Digital systems have become increasingly common in recent years. This fact accompanied by ever growing complexity of contemporary digital systems puts the new and stringent requirements on the education in this field. In order to be able to keep pace with technological innovations and changes, the future digital designers not only have to be skillful in the practical use of EDA (Electronic Design Automation) techniques but, at the same time, they have to possess solid foundations in the form of detailed knowledge and understanding of logic design basic issues. Unconventional teaching approaches and techniques are therefore required, especially in introductory courses, to make the courses' content more accessible and visible to students, and to speed up the experiments with their designs. Specially developed new intuitive tools for circuit simulation and visualization have proved their advantage in hands-on labs, allowing at the same time to ease and speed up the process of students' practical skills testing and assessing. On the other hand, the original interactive presentation tools enable to implement the new ways of content presentation based on the active learning techniques. In this contribution the research outcomes, experience with the developed and available teaching tools in the digital systems design field will be presented.**

Keywords-* *Digital Systems; Information and Communication Technology; Verification; Visualization; Tools; Skills; Interactive learning

I. Introduction and Related Work

Nowadays, digital systems are used in almost all human life applications, therefore their design, modeling, and verification methods need not only fundamental but also current knowledge to be integrated into the computer science and engineering curricula throughout the world. Education in this field has to give students the basic knowledge, the complete understanding and skills in using current design methods and professional CAD (Computer Aided Design) tools. Although EDA (Electronic Design Automation) techniques and CAD tools have a stable place in engineering education a growing number of teachers find it less than optimal to introduce them in basic introductory courses [1-4]. In fact, the complexity of these methods and tools, as well as the necessity to introduce at the same time some of the HDLs (Hardware Description Languages) may prevent the learners from understanding the basic issues of digital design. The professional tools, conceived with designers' productivity acceleration in mind, can't meet the needs of education. Therefore, especially in introductory courses, the unconventional teaching approaches and techniques are required that are emphasizing the hands-on experience and visualization.

Many teachers believe that in these courses, devoted mainly to logic circuits design, student learning can be accelerated and enhanced by the effective use of proper logic simulation tool [5-7]. The reason lies in the fact that the hardware devices, like for example breadboards, enable usually to observe just the circuits' inputs and outputs. Thus a student can connect the circuit and observe its functionality using switches and LEDs and still not understand how the logic gates are functioning [5]. The logic simulation tool on the other hand lets the students see the logic states of all the wires allowing thus for better understanding and easier debugging of faulty circuits.

Since the available laboratory time is limited it is important to minimize the time that the students spend on learning how a simulator works. For this reason, the extremely intuitive, easy to use (graphic) user interface is inevitable part of the logic simulation tool. Here the current touch-screen technology and handwriting recognition techniques bring the potential for user interface efficiency improvement, allowing thus to speed up the design process by means of properly developed design tool.

The EDA techniques and HDLs are often introduced in later courses, when the students already have the basic knowledge and skills in logic design. The HDL-based digital system design has many significant advantages e.g. clearer design with fewer mistakes, simulation based verification in early stages, or technology-independence. However, the textual form of the structural HDL model is less illustrative for human being than a schematic representation. It is usually easier to detect possible structural design errors – such as incorrect ports interconnection or an inappropriate component usage – in a circuit schematic then in textual HDL representation. Consequently, many of the professional CAD tools support the conversion of an HDL model to its schematic representation [8-12]. However, in most of these tools the simulation results can be usually represented only in waveform. In spite of high verification power of waveform representation especially the inexperienced designers, including learners in digital design courses, find it hard-to-read and difficult to reveal the potential errors in the structural HDL design. A solution to this issue could be brought by a tool that can display the simulation results directly in the schematic representation of an HDL model. The possibility to observe the data flow through the individual components of the design in the schematic representation would enable simple and effective structure verification. Such a tool would be useful especially in the educational process, namely in hands-on labs.

In recent years, several educational applications have been developed that have shown the touch-screen technology to good advantage. The majority of them represent the interactive presentation tools e.g. Classroom Presenter [13-14], DyKnow [15], or Ubiquitous Presenter [16]. The well-designed interactive presentation tools, based on the touch screen technology and mobile network communication, enable to develop the new teaching techniques, including various forms of active learning, based on interaction among teacher and students. These techniques will make the courses' content more accessible and visible to students and bring the teachers the advantage of an instant feedback.

The paper is organized as follows. In the second part, the innovative tools developed for the introductory digital design courses are presented and the experience of using them in hands-on labs will be discussed. Next, some of the education and skills based testing supporting tools for HDL course are introduced that will be followed by the dedicated interactive presentation tools. Finally, the research outcomes, and experience with the developed and available teaching tools in the digital systems design field will be summarized and future work will be outlined.

II. Introductory Digital Design Courses

At the Faculty of Informatics and Information Technologies, Slovak University of Technology (FIIT STU) in Bratislava logic circuits form an important part of two introductory courses of bachelor study programs – Principles of computer engineering course taught in the Informatics study program and Logic circuits course taught in the Computer systems and networks study program. In the hands-on labs sections of the above mentioned courses, the students are required to complete several structural assignments. Historically, real logic gates panels were used for this purpose that were later replaced by logic simulator "Log" [17] developed at the UC Berkeley. The logic simulation tool proved most of the above mentioned advantages also in these courses. However, although very powerful, it did not completely satisfy our expectations.

In general, the logic simulation tool can be enhanced introducing some other advanced features like, for example, truth tables or Karnaugh maps generation for the composed circuit that are useful for guiding the beginners in circuit design and provide additional verification possibilities. The restrictions setting concerning the usable set of logic gates and/or the number of logic gates inputs represent other enhanced feature. The possibility to set up some restrictions on the designed circuit will make the students to optimize their designs and to experiment with their versions. At the same time this feature can be helpful in the assessment process of students' assignments or in case of midterm tests to verify the students' knowledge and skills in simple logic circuit design. Another useful advanced feature is the possibility to export the designed circuit to its HDL model. Thus the basics of an HDL modeling can be introduced into the curricula at the early stage and in an easy and straightforward manner. The exported HDL model can be easily synthesized to an FPGA board, enabling thus even the beginners without much knowledge in HDL design to verify their circuits on the real hardware.

On the other hand, in the above mentioned introductory courses, the capacity required from the simulator is relatively simple. We do not require sophisticated editing abilities, but some useful features that would provide additional verification possibilities, such as above mentioned truth tables or Karnaugh maps. Other important features include the availability and portability, which will enable the students to work at home, in case they are unable to complete the assignments in the lab or they want to perform some additional experiments with the circuits.

A. Virtual Verification Panel - FitBoard

The requirements and potential advanced features mentioned above have been considered in design and implementation of the logic circuit simulation tool called FitBoard [18]. The tool was intended as a replacement of the previously used real logic gates panels with plenty o enhancements added to make the tool more focused on the specific needs of the basic courses on logic circuits design. Implemented using the object-oriented approach in Java programming language FitBoard is operating system independent, portable, with minimal system requirements in order to be suitable for older computers as well. The user settings and options are minimized, with default settings available in most cases, to keep the program usage as simple as possible. The user has to choose the set of logic gates (required in the assignment) and the available logic gates are arranged automatically on the canvas where the designed circuit has to be "wired up".

Fig. 1 illustrates the basic functionality of the tool. On the left-hand side there are four input switches providing input values in a direct and negated form. On the right-hand side there are four bulbs to signalize the output values. The bulb lights up when its input value is true. The circuit functionality should be composed of the selected NAND gates in the middle. The simulation results are refreshed each time an action is performed. The connected wires values are displayed at the logic gate inputs and at the same time the wire is colored red in case the value is true and blue indicating the value false. The resulting value and the logic functions are displayed at the logic gate output. Any wire can be selected by clicking the left mouse button on the wire. The selected wire is colored bright green, which helps to easily track the path.

FitBoard was put to a pilot run in academic year 2010/2011 in both above mentioned courses. The students were required to design simple combinational and synchronous sequential circuits using traditional design methods. In the first assignment, the students designed a converter between two numerical binary codes using the NAND gates. In the second assignment, the students designed a sequential circuit for the comparison of the two binary numbers. Altogether, more than 180 students were involved in the pilot run out of which 83 students filled out the questionnaire. Some of the questionnaire results are summarized in Fig. 2. More than 85% of the students managed to simulate the assignment circuit in the

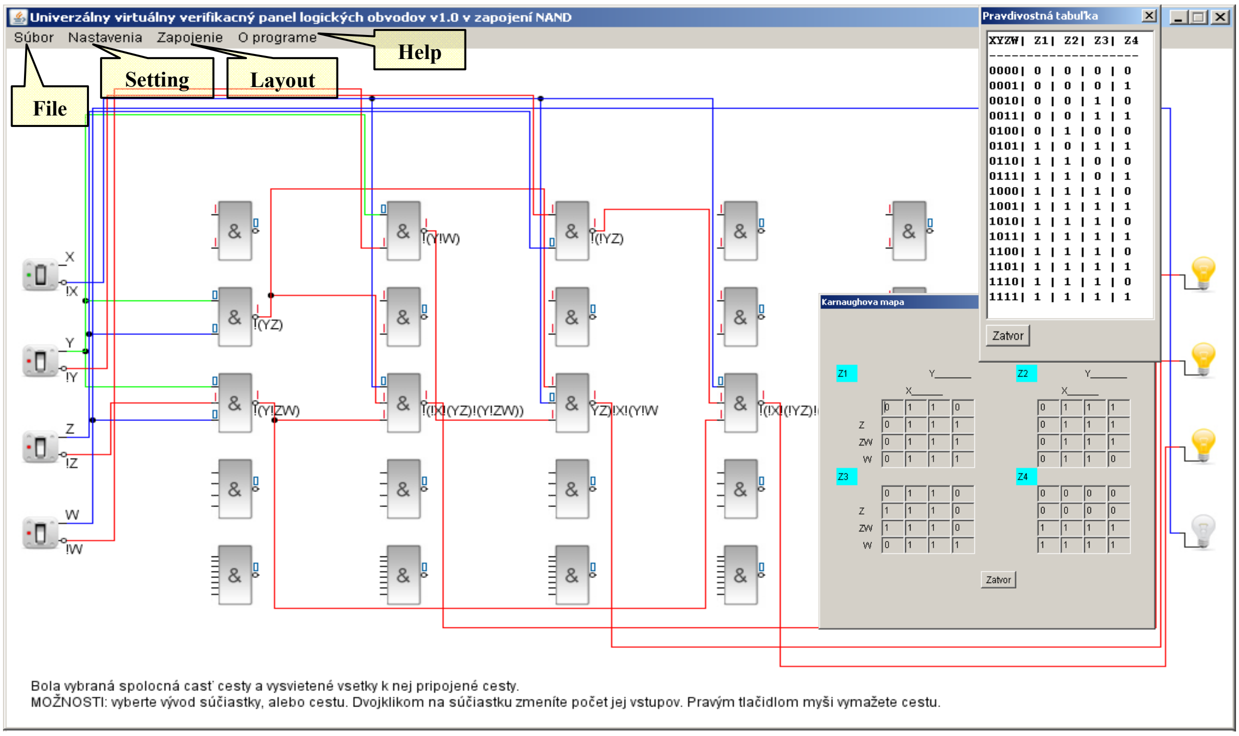

Figure 1. FitBoard user interface - the main window and the truth table and Karnaugh maps pop-up windows

FitBoard. The answers to the question "How long did it take you to understand the application logic and control?" proved the user interface simplicity and intuitiveness since 74% of students replied it took them less than 3 minutes. The automatic wire path calculation approved 69% of the students and disapproved 13% and a majority of the students consider FitBoard as good as or even better compared to the previously used logic gates simulators (each of the students used at least one).

B. ChronicLogic - Digital Circuit Design and Simulation Tool

Since FitBoard was developed as a replacement of real logic gates verification panel it shows considerable restrictions in supported circuit sizes and structures which prevents it from being used for more sophisticated logic designs. We have therefore tried to find something more appropriate for the more complex designs. However, we were not able to find a logic circuits simulator that would support the above mentioned advanced features and the touch-screen input that we recognized has the potential to improve the graphic user interface intuitiveness and effectiveness. This was the main motivation for developing a new tool for combinational and sequential circuits design using the basic elements - logic gates and flip-flops. For verification purpose the system should allow a real-time simulation of the designed circuit.

As a result the software system, called ChronicLogic [19], was developed consisting of the graphical tool for logic circuit schema development and the external simulator Icarus Verilog for its real-time simulation. Fig 3. illustrates the system's user interface and basic functions. Most of the advantages integrated in FitBoard can be found also in ChronicLogic. Unlike FitBoard the system exports the circuit into the Verilog language model, the circuit elements can be moved during the circuit design, text labels are supported to improve documenting possibilities and the system enables also to design more complex digital circuits. The simulator was designed to support touch-screen input so it can be controlled using suitably chosen predefined or user-defined gestures sketched on the touch-screen display, which makes it very natural and intuitive. In case of huge number of elements in the component library it is more efficient to use gesture to lengthy library search.

The set of tests showed the good system behavior and performance and high effectiveness of gesture recognition. The system is now ready to be included in the education process where it can be evaluated by the student users. We expect the new approach to user interface design, based on

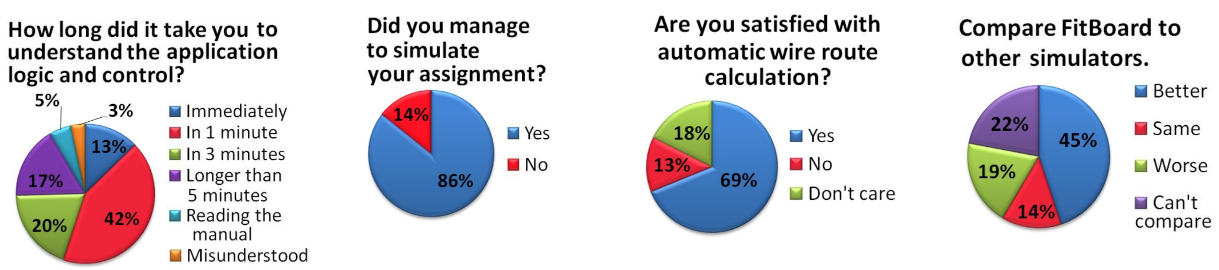

Figure 2. Results of the key questionnaire inquiries

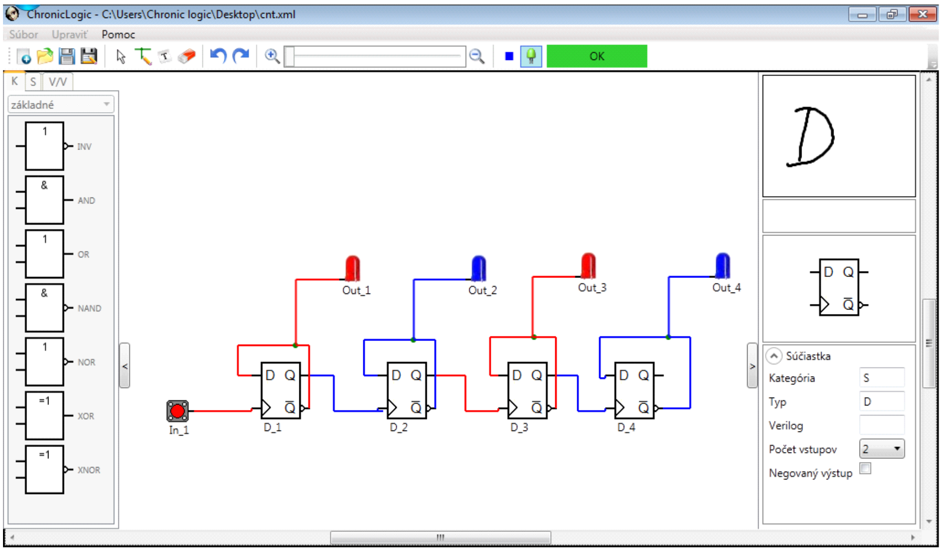

Figure 3. ChronicLogic user interface

touch screen input, will prove the user interface efficiency improvement contributing to speeding up the logic circuit design process.

III. HDL Design Course

At FIIT STU in Bratislava an HDL design is introduced in Digital systems description course in the second year of Computer systems and networks bachelor study program. In the course the students should comprehend the methods and techniques used in digital system design, and gain the skills in digital systems modelling using VHDL, SystemC, and Handel-C languages. The lab exercises of the course are based on more or less individually allocated assignments that the students can solve at school or at home using the Mentor Graphics design suite FPGA Advantage. The first two assignments are dedicated to VHDL. In the first one, the students are supposed to design a VHDL behavioral and structural models of the converter between two individually assigned binary coded decimal (BCD) codes and to synthesize it into the given FPGA board. As a sequential logic circuit the students are assigned various synchronous counters to design their behavioral and structural models in VHDL and SystemC, as well as a behavioral Handel-C model.

In the process of complex digital systems design HDLs have an inevitable role. They provide designers the possibility to describe the hardware behavior and structure on the various abstraction levels. However, the structural description in HDL form is often unreadable for students that are not yet very familiar with the HDL. In these situations a tools for graphical visualization of the HDL structural description would be very useful. Although some of the profesional development environments provide some form of design structure visualization, they are either too expensive and/or too complex to be included into the educational process. To address this issue the visualization tools for structural models in VHDL [20] and SystemC [21] have been developed at FIIT STU in Bratislava. In addition to displaying the HDL model structure the tools allow also to display the simulation results in the structure, making thus the erroneous structural models debugging much easier. Currently, the students are using these tools not only for debugging purpose but also to document their designs using corresponding schematics directly generated from their HDL models.

Another issue that had to be faced in the Digital systems description course is the course assessment process. The assignments solutions are evaluated by lab teachers and usually form a part of the overall course assessment. Since there is no way to prevent some students from cheating and different teachers might use various scales for assignments evaluation, this part of the course assessment is often neither objective nor realistic. In order to make the course assessment process more objective, fair and effective, the substantial part of the course assessment should be shifted from the assignments to the midterm and exam tests. However, at the same time, the new techniques and tools have to be developed that will allow the automated assessment of the skills based tests [22].

Some years ago we have therefore concentrated our work on designing a knowledge assessment system that would enable reliable evaluation of practical skills in the area of digital system description without substantial teacher involvement. Several testing tools have been developed and introduced into the course assesment [23-25]. In the above mentioned course students should pass three midterm tests and one final exam test. In academic year 2009/2010 the all the newly developed assessment tools were involved in the examination process for the first time. To evaluate the tools, on each midterm test, the students were divided into three groups based on the testing environment – TabletPC [23], Drag&Drop [24], or VHDL Moodle test [25]. However, the test assignment was the same, regardless of the test type. This constraint ensured that the severity of all the test types was more or less the same. Fig. 4 shows the distribution of average test attainment for the first and second midterm tests. As we can see, the students reached the best attainment in the Drag&Drop test. The reason behind this result was in the fact that in this case the correct solution is already given in the test and the students just have to find the correct statements and place them correctly into the VHDL model. For this reason the Drag&Drop test is especially suitable for testing introductory skills in the new language

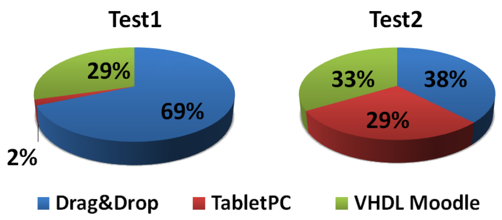

Figure 4. Distribution of average test attainment

while the other two test types are more appropriate for testing the advanced skills.

IV. Interactive Presentation Tools

Nowadays perhaps the most widespread way of giving lectures at the universities is the slides presentation using computer and data projector. The common issues concerning this type of lecture presentation include one-way static transfer of information from teacher towards students, uncomfortable ways of active entries into the presentation, low students' engagement with no feedback, and static or no access to presentation materials. A lot of lecturers noticed the declining students' engagement and an inability of students to follow the lecture content. There was an urgent need to make the lectures more attractive. However, the loss of the possibility to annotate the presentations using handwriting made it difficult.

This aspect of educational offers perhaps the largest area for improvements in education by means of current ICT and unconventional teaching approaches and techniques introduction. Technologies like handwritten text or drawing recognition, or the possibility to control computer using gestures on the touch-screen convert Tablet PCs into an interesting tool that is almost destined to be used in educational process. Combined with current wireless communication technology they represent enormous potential for improving the attractiveness of lectures and laboratory education and for various forms of interactions to come back to educational process. The Tablet PC topic is relatively new and the operating system Windows 7 was the first one fully supporting their opportunities. Therefore new applications development that will use up all their potential is an interesting challenge and the opportunity to follow the current trends in applied informatics.

These were the main reasons that encouraged the development of interactive presentation systems that would support things like attention catching marks for emphasizing slide content, writing illustrating examples, annotating diagrams, drawings or pictures as well as promoting the audience interaction [13]. That means the system that can give the audience a possibility to interfere directly with the presentation itself. Therefore, as the whole product it can help students to understand the problem by presenting the content, discussing it and interacting with it.

A. *Enhanced Classroom Presenter*

After experiencing several interactive presentation applications [13-16] we have found out that none of them fully satisfies our expectations. All the analyzed presentation systems can be characterized by poor import possibilities. If ever a tool supported other than its own natural format then it was PowerPoint presentation. So the lecture materials prepared in other format can't be reused in these systems. Since we believe this is an important restriction we decided to concentrate on this issue. The University of Washington's Classroom Presenter 3.1 (CP3) [14] was chosen as the basis for the improved presentation system, called Enhanced Classroom Presenter [26], that would satisfy our needs. The reason behind the decision was that it is an open source tool with quality interaction support. The main extensions that we have implemented into the system include: PDF documents import and export, Word document import, presentation publishing, zoom in, reflector, and slide movement functions. The possibility to copy the whole slide or just the image or text sheet layers and to paste the content of the clipboard into the presentation or current slide is also supported. The role selection was simplified, replacing the original one with a step by step role selection wizard. Fig. 5 illustrates the use of custom shape reflector on the zoomed in slide to catch the attention and explain some detail on the slide. This feature allows the teacher to show the students only a part of the slide and to focus on a specific problem.

B. *The Presenter*

Although the Enhanced Classroom Presenter satisfied our basic needs and it is still used in several courses at FIIT STU in Bratislava to introduce active learning technique into the education, it is a bit outdated concerning the utilized technologies and techniques. Therefore we decided to develop the modern interactive presentation system based on the most current technologies and techniques [27]. It was simply called The Presenter. The entire presentation system is designed for full support of Tablet PCs. The user interface is adjusted to be controlled by fingers, and thus, users will need to use stylus only in case of writing or drawing. To achieve the best quality of handwriting recognition, Windows 7 operating system API has been used. Through the dotNet 4.0 library, multi-touch gestures are recognized and used for transforming items on the slides.

The Presenter supports ink analysis and multi-touch screens, allows to export the created presentation to the

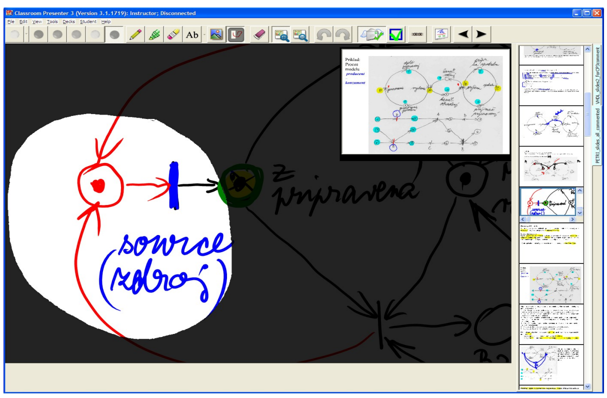

Figure 5. Custom shape reflector on zoomed in slide

portable format, and supports the instructors mode in which the instructor can use his/her own notes that are invisible to students. However, its development is not yet finished, since is does not support the full interaction among teacher and students.

V. CONCLUSION

The contribution presents a summary of research outcomes and experience with the developed and available teaching tools in the digital systems design field, namely in the three basic courses taught at the Faculty of Informatics and Information Technologies of the Slovak University of Technology in Bratislava. The efficiency of these techniques and tools have been proved in the educational process in bachelor study programs at FIIT STU in Bratislava.

Specially developed new intuitive tools for circuit simulation and visualization have proved their advantage to breadboards or other hardware devices. They allow not only to minimize the time that the students need to verify their designs, but can also ease and speed up the process of students' skills testing and assessing.

On the other hand, the original interactive presentation tools, based on the touch screen technology and mobile network communication, enable to implement the new ways of content presentation, including various forms of active learning, based on interaction among teacher and students. This kind of presentation has showed to be more illustrative, more attractive to students and brings the teachers the advantage of an instant feedback.

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