Effective Learner-Centered Approach for Teaching the Introductory Digital Systems Course

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***Abstract*—In the Internet era, students have increasingly lost interest in traditional lectures; as a consequence, their learning motivation and exam performance have decreased. The widespread adoption of learner-centered teaching methods that address this issue faces certain barriers, including: 1) the significant faculty effort necessary to prepare e-learning materials; 2) much extra time required for active online communication with students; 3) student resistance to taking an active role in their education; and 4) lecturers' common belief that learner-centered teaching activities do not allow discussion of all the required topics. This paper presents a case study based on one offering of an introductory digital systems course taught with a combination of learner-centered strategies selected to overcome these barriers and improve student performance. These measures included: 1) improving the student-teacher relationship; 2) applying intriguing, inductive, and counterintuitive approaches to introducing new concepts; 3) adopting puzzle-based quizzes integrated with peer instruction; 4) using an audience response system; 5) replacing certain lectures with tutorials; 6) reducing course duration; and 7) using a graphics tablet. The results obtained demonstrate significant improvements in lecture attendance and in student performance. The author believes that the approach presented here can benefit other engineering educators in similar courses.**

***Index Terms*—Active learning, classroom, computer science, undergraduate, instructional design, learning technology.**

I. Introduction

EFFECTIVE teaching of sophomore introductory core subjects has traditionally been a significant challenge for educators. They face obstacles, known as "faculty factors", that include intensive content-filled courses, large class sizes, and relatively small number of teaching hours; these affect student performance. From the student perspective, "student factors", otherwise known as "sophomore slump" (e.g., low motivation, poorly developed learning skills, and an assessment-focused attitude), further contribute to low achievements in various engineering disciplines [1], [2]. Given that such courses are prerequisites for many subsequent courses, faculty efforts are primarily focused on covering course content, which favors the use of conventional teaching methods, namely, prepared slide presentations coupled with blackboard explanations. These methods of teaching seldom deliver the intended learning outcomes for undergraduates [3].

This situation has worsened in recent years, partly due to a change in student attitudes and expectations toward lectures and lecturers. In the Internet era, students demand open access to course material, and are aware of the many publicly-available video lectures produced by world-renowned colleges and universities that can be studied anywhere, at any time and at a more comfortable pace. Students expect lessons from their professors to be more interesting and engaging than those available online, and seek to understand a greater proportion of course material during face-to-face lectures. Unfortunately when their new expectations encounter the same traditional lecturing style in their core lectures, students quickly lose interest and their learning motivation decreases.

To overcome these problems, instructors from various engineering disciplines have introduced more effective educational approaches, such as learner-centered teaching [4], [5] or teaching with audience response systems, ARS [6]. Published results have demonstrated the effectiveness of these new methods in a variety of different courses, including core subjects. For example, a study by Wells *et al*. [2] showed that an introduction of assessment-focused video tutorials for a computer programming course significantly improved student exam scores and satisfaction, particularly in the case of students who were not otherwise interested in the subject. In a study by Verginis *et al*. [3], tests of diverse structures and difficulty levels were successfully used to improve the final grades and student satisfaction for an introductory computer science course. An innovative approach implemented by Merrick in a similar course [7] offered a creative adaptation of puzzle-based learning to entertain and motivate undergraduate students, and to stimulate their critical thinking. The lecturer shifted focus from "teaching content" to "teaching thinking skills" by reducing the number of slides and introducing live demonstrations. Another adaptation of puzzle-based learning, combined with collaborative learning, resulted in a performance improvement in sophomore computer engineering (CE) students [8]. In a study by Reinert *et al*. [9], a variety of learner-centered teaching methods and online materials were successfully used in a semiconductor circuit design course held for electrical engineering (EE) and electrical and computer engineering (ECE) undergraduates.

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These methods included ARS, peer instruction, screencasts, lecture notes and recordings, subject literature, and faculty supervised forum. The observations made by Shekhar *et al.* [10] for sophomore engineering courses showed that instructor involvement in a variety of learner-centered teaching activities resulted in a high level of student engagement during active learning sessions.

Despite the proven effectiveness of learner-centered teaching methods and techniques, their widespread adoption in higher education has encountered resistance. Results of the surveys conducted among academics from various disciplines in the USA and Spain [11]–[14], showed that the majority of core lectures were still held in the traditional format. The researchers pointed out the following barriers to the adoption of learner-centered teaching methods: 1) less time available to cover lecture content, 2) too much effort required to prepare interactive e-learning resources and participate in online communication with students, 3) high financial costs, and 4) student resistance to active participation. These problems account for a high discontinuation rate, as the survey by Froyd *et al.* [11] showed: among ECE faculty who had implemented the learner-centered teaching methods in sophomore core courses, 25-76% reported abandoning their use.

This paper presents a case study based of one offering of an introductory course, Digital Systems 1 (DS1), in which learner-centered methods and strategies were introduced in the 2015/16 academic year. The main goal of the experiment was to reverse a downward trend in students' final grades. Over the previous three years, the average course grade had dropped from 3.45 to 3.22, only 0.22 points above the minimum pass grade of 3.0. Introduction of learner-centered teaching strategies were aimed at increasing student interest and intrinsic learning motivation while monitoring depth of conceptual understanding. Additionally, to overcome the barriers outlined above, these had to be implemented with a little extra preparation time, effort and funding. The new approach was applied in a lecture experiment conducted using 40 sophomore students majoring in Computer Science (CS) and Telecommunications with Computer Science (TCS) degree programs at the International Faculty of Engineering (IFE), Lodz University of Technology (TUL), Poland. The DS1 course consisted of 30 lecture hours and 15 laboratory hours, and fulfilled four European Credit Transfer and Accumulation System credits (ECTS credits).

The following research questions were formulated:

Q1. To what extent is the combination of learner-centered teaching methods capable of improving attendance rates?

Q2. How do student interest, learning motivation, and conceptual understanding change throughout the enhanced course?

Q3. To what extent does the new approach affect students' final grades?

Q4. Which of the applied techniques are most attractive to students?

These questions were explored using: 1) literature review; 2) observations and insights during course time; 3) student feedback; 4) attendance rate and final grades; and 5) the author's experience.

This paper is divided into four sections. Section II presents and justifies the course changes introduced, and gives the lecturer's initial observations of the effects of their application. Section III presents and discusses the effectiveness of the new approach in terms of lecture attendance and final grades, and presents the results of two student surveys evaluating the perceived interest, learning motivation, lecture quality and satisfaction with the enhanced course. Section IV summarizes findings, draws conclusions and discusses limitations; recommendations for educators are given in Section V.

II. Design Decisions

Review and analysis of related studies suggests that learner-centered teaching approaches stimulate student interest, curiosity, and intrinsic motivation to learn, thus improving the student achievements and satisfaction [3], [7], [9]. Another conclusion from studies on the teaching of required courses is that greater effort should be focused on stimulating the intrinsic motivation of these students, who typically perform worse than students who taking courses as an elective [9].

It should be noted that the majority of learner-centered teaching approaches in the literature require large amounts of extra instructor time, for example to develop interactive e-learning resources or to communicate with students via online services. These methods were excluded from this experiment, and instead classroom techniques were used as a key strategy to stimulate student interest and motivation, and to develop a good student-teacher relationship. This strategy was combined with a set of proven active learning methods [5] and some minor changes to course organization. The design decisions are presented and justified below.

A. Changes in Course Organization

A significant percentage of students do not study regularly basis, but rather increase their efforts at the end of the term and during the exam period. To motivate students to be more productive during the course, the course schedule for the DS1 lectures and labs was shortened from four to two months. This change was introduced in cooperation with the IFE study coordinator, without affecting other courses. The number of classes per week doubled, but the total number of class hours remained the same. Students welcomed this change enthusiastically by, as it lessened their study load during the exam session. A closer final exam date was another motivational factor.

Since it is well documented that tutorials stimulate student activity more effectively than lectures [9], three informal tutorials were conducted during the DS1 lectures. An obvious consequence of this was to reduce the time to cover course content. Core courses in the engineering curriculum are generally considered immutable, so reducing their content is not a practical approach. However, the rapid development of new technologies makes certain engineering concepts and topics become less important than others over time. In digital design, for example, certain instructors believe that a high level of proficiency in logic simplification, Boolean algebra, finite-state machine (FSM) optimization, or hardware description language syntax is no longer required [15], [16]. On the basis of these published findings, the DS1 course content was refined, and the following topics directed to self-tutorials: Boolean algebra theorems and transformations, expressing integers in various numeric systems and basic codes (i.e., binary, octal, hexadecimal, Gray's code, binary coded decimal, two's complement, sign-magnitude, "1 of n"), and Karnaugh map minimization. The reduction in content coverage was approximately 30%, but nevertheless the intended learning outcomes remained the same.

B. Developing a Positive Student-Teacher Relationship

The self-determination theory emphasizes the importance of relatedness in enhancing students' self-motivation to learn [17]. In the author's experience, a significant barrier to developing a student's sense of relatedness is an overuse of formal language by instructors. While this style of communication is appropriate within the scientific community, its use is not as suitable for teaching students starting their university education. A formal style obliges students to apply the same style in discussion sessions, but many students starting university avoid active participation in lectures due to their inability to communicate using formal language.

Therefore, to encourage active participation by DS1 students, the lecturer promoted a relaxed classroom atmosphere by employing more informal language and humor while transferring knowledge, and by making small digressions. For example, in starting the first lecture, the instructor joked: "*Students who want to pass must take the first rows of seats. The last two rows never pass*." The students laughed, and gathered closer - as the instructor had hoped. The same request expressed formally in the previous year: "*I encourage you to occupy the first rows to hear me better and see the blackboard*" had a poor response.

During the lecture, the instructor employed simple high school-level terminology, an appropriate strategy for teaching novices who have less developed learning capabilities than experts [18]. While introducing the two-element Boolean algebra, the lecturer said: "*You have got two numbers, zero and one. You can multiply and add them in the same way as in common algebra with one exception: one plus one equals one, not two. I advise you to remember this.*" In the initial classes, simple names were used as a replacement for new "difficult" terms, for example "disjunctive" was replaced by "sum of products" and "minterm" by "full product". The domain terminology was introduced later in the course. The instructor also "*revealed a simple recipe for combinational devices*", "*hacked the voting machine to have his vote counted twice*", and asked the students "*Got it?*" rather than "*Do you understand?*". When students answered "*Yes*" the instructor replied "*I like you*".

The relaxed atmosphere had several positive effects on student attitude. Compared to previous offerings of the course, students: 1) perceived the course as less stressful and more "friendly"; 2) were more deeply involved in discussions; and 3) were less afraid of making mistakes or displaying ignorance when participating in class discussion.

C. New Strategies for Introducing Concepts

To increase intrinsic learning motivation, new ways of introducing digital design concepts were applied. The first strategy was to adopt a learner-centered strategy based on puzzle learning [7], [19] to arouse student curiosity and interest, considered to be key brain states for efficient education [20]. One form of this strategy was to introduce a concept that students knew only superficially, in an intriguing, unexpected, and counterintuitive way. For example, the term "Boolean" is commonly believed to be a variable having only two possible values. Therefore, before introducing two-element algebra, a four-element structure was deliberately presented to surprise students.

The next strategy was to adopt an inductive style of teaching that is widely applied in the physics and chemistry communities, in which an observable phenomenon is presented first, followed by governing rules and theory that explain the phenomenon, and finally consequences are deduced [21]. In the DS1 lectures, an inductive approach was used to discuss floating point binary representations of real numbers. Demonstrations were made revealing inconsistencies in floating point calculations using the Python interpreter, for example:

```
In  :  0.1 + 0.1 + 0.1 = = 0.3
Out :  False
```

This "unpredictable" result generated substantial interest among students who listened with attention to the next presentation, which demonstrated that single precision computations can be "more precise" than double precision computations:

```
In  :  (0.1 + 0.2 - 0.3) * 100000000000000000000
Out :  0.0                          // single precision
In  :  (0.1 + 0.2 - 0.3) * 100000000000000000000
Out :  55.51115123125783    // double precision
```

Finally, using single precision numbers, it was shown that computers could make errors in addition:

```
In  :  x = 100000000.0
In  :  y = 5.0
In  :  z = x + y
In  :  print '%.1f' % z
Out :  100000008.0
```

The presentation generated excitement among students, who were eager to understand this "black magic". They eagerly asked questions and were engaged and focused on the explanations until the end of the lecture. This approach helped motivate students to learn the concepts of floating point representations of single and double precision numbers, and issues concerning rounding errors.

Other topics were discussed in a similar style aiming at arousing student interest. For example, before revealing its identity and principle of operation, the eight-input multiplexer was introduced as a black box capable of generating an arbitrary Boolean function of four variables. First, referring to the known standard design method of AND/OR/NOT gates, it was emphasized that any change in the function's truth table often results in a change in the type and number of the gates required for its implementation. The next step showed how to implement any of over 65 thousand functions of four variables using the same black box and a single inverter. Having generated students' interest by this demonstration, the functionality of the black box was explained and its identity revealed. Similarly, the iterative adder was modeled on binary addition performed by hand, and a decoder was initially presented as a minterm generator to implement multiple output digital blocks. For certain topics, it was more difficult to produce a motivating introductory concept. In such cases, digressions, comparisons or simplifications were used, such as "A processor can be thought of as a large collection of interconnected and interdependent electronic switches."

Another strategy was to provide insight on the practical value of each concept discussed. This design decision was developed on the basis of the lecturer's experience and informal student feedback. The feedback revealed that students generally considered many topics and skills from introductory courses to be unnecessary in engineering practice. For instance, classes on mathematics often include theorems and calculations without discussing their practical applications. Purely theoretical problems, such as theorem proving or determination of integrals, do not motivate future engineers to learn them. Comments on the practical importance of the presented concepts and problems were therefore frequently made during the DS1 lectures.

Special care was taken to explain the value of topics that did not obviously have practical benefits. The lecturer pointed out that solving such problems can improve students' analytical, abstract, critical thinking, and creativity skills, and enhance their engineering imagination, and it was explained that these general problem-solving skills are in demand and applicable to different areas of engineering. This approach helped to motivate students uninterested in the course.

D. New Forms of Communication and Knowledge Transfer

Previous studies have shown that continuous formative feedback is a crucial strategy for instructors to detect problems in student thinking and adopt effective countermeasures [19], [22]. The standard question and answer method is ineffective with students who avoid participation due to a fear of being judged or embarrassed in front of their peers. Therefore, to enhance the quality and quantity of student feedback, a more accepted and effective approach was adopted, namely an ARS (audience response system) [9]. The system was implemented by means of a Web-based application called Socrative [23] on students' smartphones and laptops, with no purchase or usage costs. Introduced in the sixth lecture, the ARS was welcomed by students with interest and surprise, who had previously been asked to turn off their phones. By using their smartphones and laptops during the lecture, students were actively engaged in monitoring questions asked by the lecturer and viewing cumulative results.

The ARS was also used to monitor the level of student understanding by means of anonymous quizzes throughout the lecture. The quizzes consisted of a set of questions with three possible answers, Fig. 1. A neutral answer – "I do not know" – was always included to prevent random guessing, as suggested by Bruff [6]. In each question, a familiar concept was purposely presented in a new, somewhat confusing context, similarly to puzzle-based problems [7], [19]. The answers were gathered with the Socrative ARS in its "Quick Question" mode, which required no additional preparation or configuration. The quiz questions were efficiently prepared using a WACOM graphics tablet, a low cost purchase (approximately $40). The same tablet was also used during lectures to create drawings or make annotations in real-time while discussing topics; this addressed the goal of limiting the amount of pre-prepared material to approximately 30%. A similar approach, using slides with gaps that students could fill in, was successfully implemented by Cornelius *et al.* [24] to increase final grades.

During the DS1 lectures, the instructor observed that students displayed more interest and focus when lectures were written and drawn on the tablet than when pre-arranged slides were displayed with commentary. This may have been due in part to the "novelty effect" and the fact that information was delivered at a rate that students could follow and transcribe.

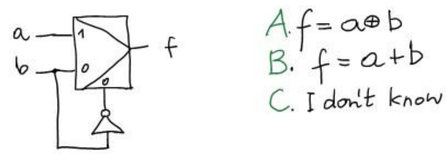

Fig. 1. A sample quiz problem (prepared using a graphics tablet).

E. Lecture Scenario

The DS1 lecture materials available online for students were the same sets of slides that were used in previous course offerings, and presented the concepts in a traditional, deductive style. The instructor told students to use the slides as a course content reference and a source for design and analysis examples, instead relying on scenarios presented during lectures. Students were not expected to read the materials before classes. The instructor also tried to include an element of surprise to each lecture, for example, by introducing a learner-centered teaching strategy or discussing different examples to those presented in the materials.

The following illustrates the typical class scenario, including all selected learner-centered strategies. To create a friendly atmosphere and increase student participation, the instructor started lectures by asking students about matters not necessarily related to the course. Sample questions, which only required single-word answers or raising a hand, are "Have you been learning digital systems over the weekend?", "Do you like attending the course?", "Who watched the film yesterday? Who did not? Who didn't raise their hand?"

Then the lecturer briefly summarized topics from the previous session and recalled the expected skills and knowledge that students should have mastered by this point.

To verify students' understanding, a short anonymous self-assessment quiz was conducted with the ARS. For each question, students were given two minutes to select an answer using their smartphones or laptops. Cumulative results were then displayed. If a collective gap in understanding was detected, a two-minute peer-instruction session among closest neighbors was conducted and the question was repeated. The instructor then briefly presented the path to the solution.

After completion of the quiz, a new lecture began with topics and concepts explained using the inductive approach "first practice then theory." For example, a simple voting machine was designed before introducing Boolean algebra, logic gates and Karnaugh maps. The machine was realized in the canonical form using AND, OR and NOT "magic" electronic elements operating according to the known sentential calculus operators $\wedge$, $\vee$, and $\neg$.

The design examples were presented mainly with the graphics tablet and chalkboard methods. PowerPoint slides were preferred while presenting underlying theory or while summarizing lectures. These teacher-centered approaches were interrupted to allow student questions and to actively involve students in problem-solving tasks. For example, students were asked to find simple truth tables, Boolean expressions or logic diagrams. Students were given two to three minutes before being asked to describe the solution aloud. The first answer was presented by the instructor on the blackboard or tablet. Students were then asked to verify the solution individually, and give alternative answers if a mistake was discovered. The instructor presented consecutive corrections until students agreed on a solution or the allowed time expired. Then the correct answer was revealed and potential student mistakes were discussed.

If at any time the lecturer noticed a drop in student concentration, the lecture was interrupted and students were asked the reasons for their diminished attention. If students remained passive, they were given the option to respond via ARS. This cumulative student feedback allowed the lecturer to make modifications on the fly. For instance, in certain cases the PowerPoint presentation was interrupted and the tablet was used to thoroughly illustrate more difficult topics. The instructor also encouraged students to contact him during office hours or immediately after the lecture if they still had gaps in understanding. Interestingly, for most students preferring the latter option, two- to three-minute individual explanations were sufficient to fill these knowledge gaps. After each lecture 15 minutes were allocated for this activity.

III. Results and Discussion

In order to answer the research questions *Q1* and *Q3*, attendance in lectures and student final grades were compared with the results from the previous offerings of the course. The solutions to the remaining questions were found using two anonymous student surveys; these were conducted in 2015/16 for the first time, so their results could not be compared with previous academic years. The enhancements to the DS1 course could not be postponed in order to collect the appropriate reference data because the poor student performance in 2014/15 forced the course manager to intervene promptly.

The surveys, S-1 and S-2, were carried out in the third and ninth (final) weeks of classes. Both surveys examined how students' interest, motivation, and conceptual understanding had evolved over the period of classes, using simple questions – "How do you assess the current level of your interest/motivation/understanding?" In the S-1 survey, students were also asked about their initial assessments – "How did you assess your interest/motivation level *before* the beginning of the course?" In the S-2 survey, students also rated the quality of the lectures – "How do you rate the quality of lectures?" and their overall satisfaction – "What is your level of satisfaction with the course?" Additionally, students were asked a question concerning the teaching techniques and communication methods used by the instructor.

Q1: Improvement in Student Attendance Rate

Since lecture attendance did not count towards the grade, attendance was used as a proxy for the attractiveness of course content and teaching methods. The attendance lists were generated easily using a contactless reader of student ID cards and the associated specialized software available at TUL. The distribution of the DS1 attendance rate is comparted to rates obtained in the previous year, Fig. 2. Rates are missing for lectures 3, 11, and 14 from 2014/15, due to a lack of attendance records. The results reveal that the learner-centered teaching approach used in 2015/16 attracted a consistently higher percentage of students to the lectures than in 2014/15. Equally important is an initial increase in the attendance rate from approximately 90% to 100% during the fourth lecture. This is a rare phenomenon among required courses at TUL, where a gradual decline in attendance is usually observed during the first few weeks of classes.

The improvement in average attendance rate was confirmed as statistically significant using the Welch's unequal variances t-test. The results of the statistical analysis are summarized in Table I, which shows the number of samples, *n*, sample means, $\overline{M}$, and sample variances, S^2, of the attendance rates in 2014/15 and 2015/16. The *p*-values were calculated separately for two cases: 1) the data for lectures 3, 11 and 14 being excluded from the analysis; 2) all available samples being included in the test. In both cases the *p*-values are less than 3×10^{-7}, confirming a significant improvement in average lecture attendance rates.

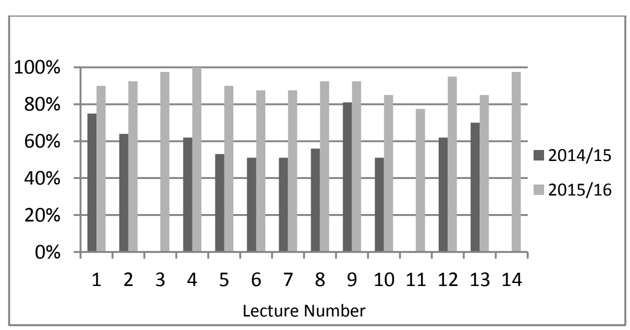

Fig. 2. DS1 lecture attendance rate in 2014/15 and 2015/16 (for lectures 3, 11,

and 14 during 2014/15, attendance lists were not recorded).

TABLE I
RESULTS OF STATISTICAL ANALYSIS OF LECTURE ATTENDANCE RATES

Year	n	$\bar{M}$	S^2
2014/15	11	61.10	98.1
2015/16*	11	90.68	20.1
2015/16	14	90.71	35.9

Year	**2014/15**
2015/16*	$p < 4\times10^{-7}$
2015/16	$p < 3\times10^{-7}$

n = number of lectures, □ = attendance rate mean, $\square^2$ = attendance rate variance, p = p-value, *data for lectures 3, 11 and 14 excluded from analysis

Q2: Interest, Motivation, and Conceptual Understanding

The results of the surveys showed an increase in the level of student self-reported interest, motivation, and understanding with the learner-centered teaching approach, Fig. 3. The average level of interest, on a range of 1 to 5, increased from an initial value 2.54 before the lectures started, to 3.83 in the third week of classes. It should be emphasized that this effect occurred within the first five lectures after implementing new course organization and learner-centered techniques. In the final week of classes, the average level of interest increased to 4.05.

Along with the increased level of student interest, the average level of learning motivation also grew, but was always lower than the level of interest. This interest-motivation relationship was discovered in each individual student questionnaire, so it can be inferred that certain factors exist that reduced motivation relative to intrinsic interest.

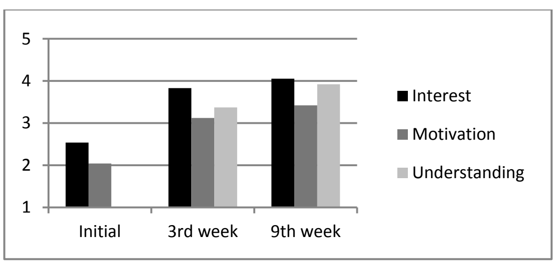

Fig. 3. Evolution of the average level of student self-reported interest, learning motivation, and conceptual understanding within the DS1 course on a scale from 1 to 5 (lowest to highest); the initial *understanding* level was not measured.

Some demotivating factors were pointed out by students in the S-1 survey open-ended question: "What do you think would help you to reach a higher degree of learning motivation?". The most common answers were: "Lack of sleep causes lack of concentration at the lecture", "I feel unmotivated, this is not a course for me", "I need to know exactly what to learn and what to do", "I need to understand the concepts during the lecture". In the S-2 survey, students gave course-specific answers to this question: "Too few practical examples", "Too few points for homework". These results reveal that the new approach encouraged students not only to learn the course but also to critically assess its manner of teaching. The perceived average understanding level recorded the highest increase between the third and the ninth week of classes, 0.55, compared to the corresponding increase in interest level, 0.22, and motivation level, 0.30.

Q3: Improvement of final grades

A key evaluation of the new approach was a comparison of student final grades with the results from three previous course offerings. The final exam consisted of two parts, Combinational Systems containing five problems, and Sequential Systems containing three problems. These two exam parts were performed during two separate days and were combined into a single grade. Approximately 20 different versions of the exam of similar difficulty were on hand and one was selected for all students during the evaluation. These versions were developed in 2009 and have since been used without significant modification.

In the compared years, the problems on the Sequential Systems exam included: analysis of a two-state FSM from a logic diagram, synthesis of a two-state FSM from a state transition diagram (STD), and deriving the STD from a functional specification. The Combinational Systems problems were more diverse and could not be kept as consistent for the years studied. However, they verified two skills that were directed to self-tutorials in 2015/16, namely Karnaugh map minimization and Boolean algebra transformations. For all course offerings considered, the person grading the exam, the stated learning outcomes, and the assessment criteria, were all consistent.

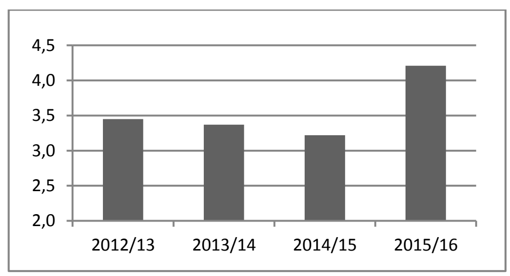

Fig. 4 Average course grade for academic years 2012/13 to 2015/16, scaled from 2.0 to 5.0 (lowest to highest).

As shown in Fig. 4, the average student grade obtained during the 2015/16 experiment was the highest of the last four years of course offerings. In comparison to the preceding year, 2014/15, the final mark improved on average by one, in the range of 2 to 5. A statistical analysis of the grades is summarized in Table II. For comparison purposes, the number of grades, n, grade means, $\bar{M}$, grade variances, S^2, and two-tailed Welch's test p-values are presented for six different pairs of datasets. The results confirm the statistical significance of the 2015/16 grade improvement with respect to each of the preceding years (p-values lower than 3×10^{-4}). Moreover, differences in grades within previous years were not statistically significant (p-values higher than .2). The results presented here and in Section II.Q1 support the existing research findings of a close relationship between class attendance and student performance [25].

TABLE II
RESULTS OF STATISTICAL ANALYSIS OF STUDENT GRADES

Year	n	$\bar{M}$	S^2
2012/13	53	3.45	0.66
2013/14	45	3.37	1.08
2014/15	46	3.22	1.11

Year	**2013/14**	**2014/15**	**2015/16**
2012/13	p=0.665	p=0.226	$p<2\times10^{-4}$
2013/14	-	p=0.504	$p<3\times10^{-4}$
2014/15	-	-	$p<3\times10^{-5}$

2015/16	40	4.21	1.01

n = number of grades, $\bar{M}$ = grade mean, S^2 = grade variance, p = p-value

Q4: Attractiveness of the Learner-Centered Teaching Technologies

The ARS system received high scores in the student survey.. The instructor noted that during quizzes the neutral answer “I don’t know” was never selected, suggesting that students were kept engaged throughout the sessions, as though they were taking part in an interesting game, and thus avoiding the neutral answer, as constituting a form of “resignation” from the activity. On the other hand, some students lost interest while using the ARS for a longer period of time.

Fig. 5 shows students’ response to the question: “Select two among the following lecturing forms that best suit your needs: 1) slide-by-slide presentation; 2) chalkboard method; 3) drawing slides with a graphics tablet; 4) in-class discussion; 5) other (please describe)?” Note that students preferred the tablet to all the other methods. Informal feedback from a group of students revealed that tablet, blackboard, and discussion were better suited to their ability to follow the lecturer due to their inherent slower rate of information transfer. Their preferred technique, the use of a graphics tablet (38%), fared higher than its analog, the traditional chalkboard method (18%). Apart from its novelty, students may have appreciated the tablet method for its easy readability on large screens in lecture halls. Similar results are presented in a study by Carrillo *et al.* [26].

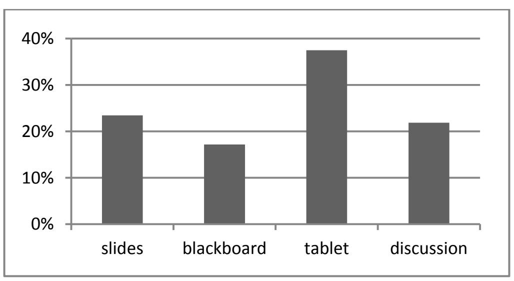

Fig.5. Preferred lecturing methods among students.

IV. Summary and Conclusions

This case study has demonstrated that an implementation of learner-centered strategies and technologies within an introductory digital systems course led to a significant improvement in lecture attendance and student performance. In the experiment, an approximately 50% increase in average attendance rate and 30% increase in student average final grade over previous offerings of the course were obtained.

In addition to this evidence of effectiveness, the teaching methods applied also have the benefit of requiting only a relatively small amount of extra preparation and management time, making the approach acceptable by a larger proportion of instructors. However, certain limitations should be considered while interpreting the results of the study.

First, the selected teaching methods were assessed holistically, so there is no means of knowing which strategies were most effective and which had little or no influence on learning. Secondly, the enhanced teaching has been shown to be effective only in terms of lecture attendance and final grades. Its impact on improving student interest and motivation was not examined because the appropriate reference data were not gathered in previous offerings of the course. Thirdly, because the laboratory section of the course, conducted by the same instructor, used the same teaching methods as in the previous offerings, the effect of the laboratory was not considered. However, the improvement in student-teacher relationship could have had an effect on the level of understanding that students achieved during the lab sessions. Fourthly, student characteristics could have had an influence on the results. For example, the attendance rate at the first lecture in 2014/15 was lower than in 2015/16, a possible indicator of different student attitudes toward the course during these offerings.

Some of the teaching strategies presented, such as informal tutorials, maintenance of good student-teacher relationship, and use of the ARS with peer instruction, can be easily transferred to other courses and institutions. The adoption of the remaining strategies may face certain difficulties: 1) compressing the classes from four to two months may be difficult to realize at other institutions; 2) a 30% reduction in content coverage may be a barrier for certain lecturers; 3) the rationale for using graphics tablet or puzzle-based quizzes depends on the course content; 4) intriguing and inductive lecturing may be difficult to realize for certain topics.

V. Recommendations

While the effectiveness of the applied learner-centered strategies was assessed holistically, the experience gained during the study has led to some recommendations concerning individual techniques.

A crucial teaching approach is to develop and maintain a friendly environment in which students feel less afraid of speaking or asking questions in class. The instructor observed that student engagement increased the most when informal language and a sense of humor was used during teaching. This technique, however, was also the most challenging for the instructor to implement consistently.

Reducing the duration of classes may be simpler to realize than is often perceived, and can be done without affecting other courses in the program. Ideally this would be done in cooperation with the study coordinator, but if necessary the instructor can organize weekly additional informal classes with student consent - a widely accepted practice at TUL.

The necessary reduction in content coverage may be realized in two ways: 1) by removing less relevant or outdated topics from the syllabus; 2) by directing some relatively simple topics to self-tutorials, which requires the knowledge and skills to be gained by students to be precisely defined.

Implementation of intriguing and inductive styles of introducing concepts, puzzle-based self-assessment quizzes and the ARS are recommended first-line strategies because they can trigger and maintain student curiosity, interest and motivation. Subsequent teaching methods should be added gradually and used interchangeably for novelty and a surprise effect to further enhance learning. Some experimentation with various learner-centered methods is suggested here, including project-based learning or online interactive learning. These methods were not considered in the study but they may benefit from adjustability of learning pace and style. Further increase in student motivation may be obtained by a demonstration of lecturer's enthusiasm and engagement.

The amount of extra time required to prepare quizzes and new lecture scenarios depends on the teacher's experience and the course characteristics. In this study, the DS1 lecturer, who had 16 years of teaching experience, incurred approximately ten hours for this work. In the end, it is up to the instructor to decide how much time and effort he or she is willing to devote to enhance teaching. As an incentive for pedagogical experiments, commentary from three students is included here: "*There was a high level of dedication and passion from lecturer that motivated me to learn.*", "*The best lecturer and subject to date; thank you very much.*", "*It is a scandal that the subject had to end so soon! It should have lasted longer*!"

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