Online Discovery/Constructivistic Learning Using Cognitive Tools in Mathematics’ Higher Education

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Abstract—This paper analyzes online discovery learning/constructivistic approach using cognitive tools in higher Mathematics’ education, via a combination of electronic worksheets designed and implemented in Mathematica and online synchronous communication via the tools of a Learning Management System (LMS) and voice and video group calls. Moreover, the paper presents empirical research results of a case study concerning the approach’s application at the Department of Statistics and Insurance Sciences of the University of Piraeus and focuses on students’ attitudes towards the approach. We used a mixed approach in the study, in particular a quantitative approach with open-ended questions. A questionnaire was handed out and was answered by the students that participated. We performed statistical analysis via SPSS to data obtained by questions with binary answers and answers on a 7-point Likert scale. Also we included several open-ended questions, in order for the students to express their views and attitudes towards the benefits and the disadvantages of the tools and the approach used.

Index Terms—Discovery Learning, Constructivism, Cognitive Tools, Online Discovery/Constructivistic Learning, Learning Management Systems, Synchronous Communication, Asynchronous Communication.

I. INTRODUCTION

Cognitive tools (or mindtools) are recognized by instructional technology researchers as the concept that can describe most appropriately the computer learning environments they design or use, in order to enhance learning, performance, and understanding; both by researchers that design or utilize artificial intelligence technologies in student modeling and by researchers that design constructivistic activities that promote discovery learning, exploration and social interaction [1]. Cognitive tools are computer learning environments that students can use while they are studying any subject; students can use and utilize the structure and the “logic” of the tool, in order to study the concepts, the properties and the principles of the subject. In this direction, cognitive tools function as intellectual partners of the students, as they are involved in discovery learning/constructivistic activities [2].

Discovery learning supports environments where students “discover” the various concepts and ideas and the principles and properties of the concepts and the quantities they study, via a process of exploration and experimentation [3], [4]. In Abrahamson & Kapur [5], different educational research projects which support the principles of discovery learning are discussed, yet they are based on different philosophical stances and theoretical constructs.

Constructivism supports learning environments where students actively “construct” the various concepts and ideas, based on their preexistent knowledge and beliefs; knowledge is a process of adaptation with the world of experiences and not the discovery of a pre–existent world. The Social development theory of learning supports environments where students learn the various concepts and ideas initially “socially” and afterwards individually, as a process of internalizing these concepts and ideas [3], [4]. Social Constructivism, as analyzed in Kim [6] and Amineh & Asl [7], emphasizes on the importance of culture and context in understanding what occurs in society and on constructing knowledge based on this understanding; understanding, significance and meaning are developed in coordination with other human beings.

Online discovery/constructivistic learning approach using cognitive tools is based on Discovery learning, Constructivism, the Social development theory, Social Constructivism and the concept of using computers as cognitive tools; moreover, the approach supports the design and implementation of learning activities that can take place while the teacher and the students are at a distance one from the other, yet they can communicate synchronously via the tools of an online Learning Management System (LMS) and group voice and video calling and conferencing.

An LMS System supports online learning providing tools for learning management, monitoring students’ participation and performance, delivering content, handing out and receiving work and tests to/from students, communication etc. LMS systems’ characteristics as their general structure, types and most common features are described and analyzed in Cavus [8].

This paper proposes an approach that combines electronic worksheets designed and implemented in Mathematica and online synchronous communication via an LMS system and group voice and video calls. Moreover, the paper presents a case study that took place at the Department of Statistics and Insurance Sciences of the University of Piraeus concerning the approach’s application at Mathematics’ courses and focuses on students’ attitudes towards the approach. A mixed approach was selected for the study, in particular a quantitative approach with open-ended questions. A questionnaire was handed out and was answered by the students that participated in the study. We performed statistical analysis via SPSS to data obtained by questions with pre-defined answers. Also we included several open-ended questions in order to identify in a greater extent the students’ views and attitudes towards the benefits and the

Published on February 17, 2020.

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DOI: http://dx.doi.org/10.24018/ejers.2020.0.CIE.1796
disadvantages of the tools and the approach used.

II. ONLINE DISCOVERY/CONSTRUCTIVISTIC LEARNING VIA A COMBINATION OF SYNCHRONOUS COMMUNICATION TOOLS AND COGNITIVE TOOLS

The online discovery/constructivistic learning approach via a combination of synchronous communication and cognitive tools supports the parallel use of: (i) Electronic worksheets in the environment of a cognitive tool, with which each student works on his/her own computer at a distance and (ii) a communication system in the environment of an LMS system in combination with voice and video calling and conferencing, via which, students can interact with each other and with the teacher, discuss, exchange views, formulate ideas and questions and draw conclusions through experimentation and active engagement with the worksheet. The communication system should offer possibilities for: a) exchanging text messages, b) sending documents and files between users, c) conducting video/voice conversation, c) using “Whiteboard” applications (through which the teacher and students can write and draw simultaneously on a table in real time).

The electronic worksheets in the environment of a cognitive tool are advisable to include [3], [9]:

- Activities that via steps, actions and questions, guide learners to the experimentation with the concepts, to the formation and checking of conjectures and to the formulation of general conclusions through discussion.
- Basic commands of the cognitive tool and the required programs for the subjects being studied.
- Suggestions about the subject being taught and the functions of the cognitive tool.
- Exercises that can be solved with the use and modification of the commands and programs that are already contained in the worksheet.

Below in Fig. 1, snapshots of an electronic worksheet in Mathematica that was used in the case study are presented.
Cognitive tools that can be used in designing and implementing electronic worksheets amongst others are Mathematica, Geogebra and Octave. Results on students’ performance in higher Mathematics’ education, when electronic worksheets in the environment of cognitive tools are introduced in discovery learning and constructivistic activities, have been reported amongst others by Korres [9], [10]. The use of electronic worksheets in discovery learning and constructivistic activities proved to have a positive impact on students’ performance mainly on interpretation of results and application of procedures, compared to traditional instruction.

Students’ attitudes towards the discovery learning/constructivistic approach using electronic worksheets, for face-to-face instruction in the computer laboratory, in higher Mathematics’ courses, have also been previously studied [3], [10]. The results showed positive attitudes by the students towards the cognitive tool used (Mathematica), towards the characteristics of the teaching approach relatively to the principles of discovery learning/constructivism and towards the development of higher order thinking skills supported by the approach; they expressed neutral and slightly negative attitudes regarding whether they can use the tool independently of the presence of the teacher.

Geogebra’s interface and manipulation make it more appropriate for secondary education (highschool and junior highschool) and the last classes of Primary school; it can also be used in tertiary education. Octave and Mathematica, which can also function as programming languages, are more appropriate for tertiary education and upper secondary education.

The online discovery/constructivistic learning approach was applied at the Department of Statistics and Insurance Sciences of the University of Piraeus. A server was created on the website of the Department, where E-Class platform by the Greek Universities Network (GUNet) was installed. E-Class by GUNet is an LMS system that offers possibilities for both asynchronous and synchronous communication and the design and implementation of e-learning courses. The LMS system was accessible through the url http://e-learn.sta.unipi.gr, that was created for the purposes of the study and is currently inactive. Two e-courses were created on the E-Class platform, Calculus II and Algebra, while access to these courses was controlled.

Another LMS system that could be used in creating e-courses and offers possibilities for both asynchronous and synchronous communication is Moodle. Moodle is an open source LMS system that is widely used for the design and implementation of e-learning courses. Moodle’s characteristics are described and analyzed in Cavus [8]. Synchronous communication between teacher-students and between students can be established via a combination of the “Chat” application of Moodle and an app which supports voice and video group calls.

Skype offers possibilities for voice and video group calls, including conference calling and group chats that can host a group video chat or conference call for up to 50 participants. Also with group screen sharing, someone can present Powerpoint slides, video recordings or other material to the whole group. Other tools that can be used for group voice and video calls are Zoom, which supports up to 100 to 1000 participants depending on the plan, Facebook Messenger, which supports up to 50 participants and Apple’s FaceTime, which currently supports up to 32 participants on group calls.

III. METHODS

The case study involved the application of discovery/constructivistic learning approach using electronic worksheets at the Department of Statistics and Insurance Sciences, of the University of Piraeus, to the undergraduate course Calculus II. The cognitive subjects selected are partial derivatives and multiple integrals, since they are basic subjects in the curriculum of Mathematics’ and Sciences’ Departments, Polytechnic Departments and most Economic Studies’ Departments.

An experimental program was designed and implemented for students who signed up for the e-course Calculus II at the E-Class platform. The program utilized both asynchronous and synchronous communication; in particular, it consisted of three parts: (a) teaching theoretical subjects, through the traditional narrative approach enriched with the features proposed by contemporary views on learning and teaching, conducted by face-to-face teaching on campus, (b) teaching theoretical subjects through asynchronous communication, with educational material that students could download from “Documents” at the LMS system and through exchange of opinions, ideas and queries raised by the students in “Discussion area” and c) teaching properties, geometric interpretations, processes and applications of theoretical issues via online discovery/constructivistic learning approach with the parallel use of (i) electronic worksheets in Mathematica which students downloaded from the LMS system and each student worked with on his/her computer and (ii) “Chat” at the LMS system in combination with group voice and video calls via which students could interact with each other and with the teacher, discuss, exchange ideas, formulate ideas and questions and draw conclusions through experimentation and active work with the worksheet.

The research questions of the study are:

1. What are the students’ attitudes towards the implementation of online discovery/constructivistic learning approach using electronic worksheets regarding: a) the cognitive tool used (Mathematica), b) the characteristics of the LMS system used (GUNet E-Class), c) the characteristics of the

Fig. 1. Electronic worksheet in Mathematica

DOI: http://dx.doi.org/10.24018/ejers.2020.0.CIE.1796
approach relatively to the principles of discovery learning and constructivism and d) the development of higher order thinking skills supported by the approach?

2. What benefits and disadvantages do students identify on the tools used and on the approach?

The sample of the study included the students that signed up for the e-course Calculus II at the E-Class platform; 21 students participated at the study. After the completion of the experimental program, a questionnaire was given at the students that participated.

In Korres [9], characteristics of an online distance learning program via a combination of synchronous and asynchronous communication are presented and analyzed and the questionnaire used in the study is presented and analyzed. The questionnaire contains four parts: (I) Students’ attitudes and experience towards computers’ use, (II) Characteristics of the LMS system used, (III) Characteristics of the cognitive tool used and (iv) Characteristics of the online approach regarding: A. Characteristics of discovery/constructivist learning, B. Characteristics of developing higher order thinking skills and C. General characteristics. Most questions had answers on a 7-point Likert scale, with 1 corresponding to Disagree and 7 corresponding to Agree. A small number had binary answers (Yes, No). Also there were several open-ended questions, via which students expressed their views and attitudes regarding benefits and disadvantages of the tools used and the approach.

Mixed methods’ research generally refers to the processes of collecting and analyzing both qualitative and quantitative data in a single research project [11]. In Haq [12] qualitative, quantitative and mixed methods in social research are presented, analyzed and compared and the mixed methods’ approach is presented as the most appropriate for studying and explaining complex social phenomena. Even though educational research has similarities, but is not social research, a mixed methods’ approach relatively to the principles of discovery learning and constructivism and the development of higher order thinking skills supported by the approach.

IV. RESULTS

A. The students that participated in the study

21 students participated in the study; 15 (71.4 %) were males and 6 (28.6 %) females.

Regarding the students’ experience in using computers, 52.4 % used computers from 1 to 3 years and 47.6 % for more than 3 years. Regarding the students’ interest in using computers, the total of students showed positive attitudes (5 and above); moreover 90.5 % gave totally positive answers (6 or 7).

B. Students’ attitudes towards the LMS system used

Students’ attitudes were positive towards almost all questions regarding the LMS system used. Answers were almost equally distributed between positive and negative attitudes, slightly towards positive attitudes, only to the question whether the students can use the LMS system independently of the online presence of the teacher (Table I).

| TABLE I: STUDENTS’ ATTITUDES TOWARDS THE LMS SYSTEM USED |
|-----------------------------------------------------------|
| Positive attitudes | Neutral attitudes | Negative attitudes |
|---------------------|---------------------|---------------------|
| 1. Is the LMS system easy to start? | 100 % | - | 0 % |
| 2. Are the LMS system’s functions easy to operate? | 71.4 % | 28.6 % | 0 % |
| 3. Can you use the LMS System independently of the online presence of the teacher? | 57.1 % | - | 42.9 % |

According to students, the prerequisite knowledge and skills for using the LMS system are mainly computer experience (61.9%) and secondarily programming (14.3%) and specific command knowledge (9.5%). 38.1% of students stated that no previous knowledge and skills are required.

The ways via which students learned to operate the LMS system, as they stated, are mainly via direct manipulation (57.1%) and with the help of a third party who has experience in corresponding systems (42.9%), secondarily via using a manual (23.8%).

C. Students’ attitudes towards the cognitive tool used

Students’ attitudes were positive towards almost all questions regarding the cognitive tool used (Mathematica). Answers were equally distributed between positive and neutral attitudes only to the question regarding the help browser of the tool (Table II).

| TABLE II: STUDENTS’ ATTITUDES TOWARDS THE COGNITIVE TOOL USED |
|---------------------------------------------------------------|
| Is the tool… | Does the tool… | Positive attitudes | Neutral attitudes | Negative attitudes |
|---------------------------------------------------------------|
| 1. … easy to start? | 85.7 % | - | 14.3 % |
| 2. … easy to operate? | 76.2 % | 14.3 % | 9.5 % |
| 3. … easy to learn? | 61.9 % | 23.8 % | 14.3 % |
| 4. … have simple formalism? | 80.9 % | 9.5 % | 9.5 % |
| 5. … have dynamic formalism? | 76.2 % | 23.8 % | 0 % |
| 6. … generalizable? | 47.6 % | 38.1 % | 14.3 % |
| 7. How would you characterize the clarifications and explanations of the software regarding errors in data entry, from insufficient to adequate? | 61.9 % | 14.3 % | 23.8 % |
| 8. How would you characterize the Help Browser, from insufficient to adequate? | 38.1 % | 38.1 % | 23.8 % |
| 9. Can you use the tool independently of the presence of the teacher? | 68.4 % | - | 31.6 % |

According to the students, the prerequisite knowledge and skills for using the tool are mainly knowledge of software commands (57.1%), secondarily experience in the operation of the tool (38.1%) and programming knowledge (38.1%). 14.3% of students stated that no previous knowledge and...
skills are required.

D. Students’ attitudes towards the characteristics of the approach relatively to the principles of discovery learning/constructivism

Students’ attitudes were positive towards all questions regarding the characteristics of the teaching approach relatively to the principles of discovery learning/constructivism (Table III).

TABLE III: STUDENTS’ ATTITUDES TOWARDS THE APPROACH’S CHARACTERISTICS RELATIVELY TO THE PRINCIPLES OF DISCOVERY LEARNING/CONSTRUCTIVISM

| Did the teaching approach … | Positive attitudes | Neutral attitudes | Negative attitudes |
|-----------------------------|--------------------|-------------------|-------------------|
| 1. … provoke your interest for the lesson? | 100 % | 0 % | 0 % |
| 2. … provoke your interest for Mathematics as a subject? | 85.7 % | 0 % | 14.3 % |
| 3. … permit you to participate actively to the lesson? | 90.5 % | 9.5 % | 0 % |
| 4. … permit you to self – act? | 76.2 % | 9.5 % | 14.3 % |
| 5. … permit you to experiment with the concepts and their characteristics? | 71.4 % | 28.6 % | 0 % |
| 6. … provide opportunities for the formulation and checking of conjectures? | 76.2 % | 0 % | 23.8 % |
| 7. … permit you to reflect on the concepts and the activities you got involved with? | 85.7 % | 0 % | 14.3 % |
| 8. … permit you to create personal representations of the concepts taught? | 76.2 % | 14.3 % | 9.5 % |
| 9. … give the opportunity for conversation between the teacher and the students? | 81 % | 19 % | 0 % |
| 10. … give the opportunity for conversation between the students? | 77.8 % | 22.2 % | 0 % |

In the question of how students would characterize teacher support through online synchronous communication, with answers on a 7-point Likert scale from Incomplete to Adequate, all students rated support as adequate (answers 5 and above); moreover, totally positive responses (6 or 7) were expressed by 90.5% of the students.

On the question of how students would characterize the degree of guidance from the electronic worksheet, with answers on a 7-point scale from minimum to complete guidance, all students rated the degree of guidance as high (answers 5 and above); in fact, 90.5% of the students expressed totally positive answers (6 or 7).

E. Students’ attitudes towards the characteristics of the approach relatively to the development of higher order thinking skills

Students’ attitudes were positive towards all questions regarding the development of higher order thinking skills supported by the approach (Table IV).

TABLE IV: STUDENTS’ ATTITUDES TOWARDS THE DEVELOPMENT OF HIGHER ORDER THINKING SKILLS SUPPORTED BY THE APPROACH

| Did the teaching approach permit to you … | Positive attitudes | Neutral attitudes | Negative attitudes |
|------------------------------------------|--------------------|-------------------|-------------------|
| 1. … evaluate information and ideas? | 61.9 % | 38.1 % | 0 % |
| 2. … analyze information or ideas? | 47.6 % | 42.9 % | 9.5 % |
| 3. … combine information or ideas? | 71.4 % | 28.6 % | 0 % |
| 4. … elaborate on information or ideas? | 57.1 % | 14.3 % | 28.6 % |
| 5. … to synthesize ideas? | 57.1 % | 42.9 % | 0 % |
| 6. … imagine ideas? | 57.1 % | 42.9 % | 0 % |
| 7. … deal with problem solving? | 57.1 % | 42.9 % | 0 % |
| 8. … design actions and assess their results? | 71.4 % | 28.6 % | 0 % |
| 9. … make decisions? | 47.6 % | 38.1 % | 14.3 % |

F. Students’ attitudes towards the general characteristics of the approach

On the question of whether they believe that online learning with synchronous communication substitutes sufficiently classroom instruction, students were divided into positive and negative attitudes (with both percentages 38.1%); 23.8% of the students did not take a position (neutral answers).

When asked if they would choose to attend another course with asynchronous communication (communication not at real-time), another course with online synchronous communication (real-time communication) and another course using cognitive tools with similar functions, all students who answered each question gave positive answers.

G. Benefits and disadvantages of the tools and the approach used as stated by the students

Below we present some of the benefits/advantages of learning via an asynchronous communication LMS system compared to traditional teaching, as stated by students:

- “Easy communication and fast exchange of views. Use of software to make the lesson easier to understand”.
- “Bridging gaps at any time”.
- “The platform is very useful, as long as you know how to handle it. From there on, it becomes a valuable tool”.
- “Customizable in the case of small groups. Someone can view lesson’s concepts in representations, visualize mathematical concepts, he/she can understand the applicability and some of the possible applications of Calculus. It greatly increases someone’s interest to deal more extensively with the lesson and its applications, in areas of interest to him/her”.
- “There is time to practice on our own, find the answers
on our own and remember them better”.

- “You are repeating and learning new things that you want at any time of the day. You can easily get in touch with the teacher, without having to look for him from office to office”.

- “Data representation, familiarity with modern technology, time saving, excellent understanding of the course”.

Below we present some of the disadvantages of learning via an asynchronous communication LMS system compared to traditional teaching, as stated by students:

- “The environment, as well as its operations, is quite difficult. That is, the commands are quite difficult and you cannot deal with them without notes, teacher instructions or brochures. Even when something goes wrong, there is not an error message, which is quite time consuming and tiring”.

- “It is not easy for the teacher to give a quick answer to a query or an example and much more since we are talking about mathematics, where symbols make it more difficult; it is time-consuming to transfer formulas, examples of answers to queries, symbols etc”.

- “Lack of personal immediacy”.

- “Not all students participate”.

Below we present some of the benefits/advantages of the online discovery/constructivistic learning approach that combines synchronous communication and cognitive tools, compared to traditional teaching, as stated by students:

- “Instant communication, collaboration, teamwork”.

- “We understand graphical representations and concepts better and communicate more and more openly with our teacher and fellow students. We can ask the teacher in real time more questions and correspondingly have more answers and clarifications”.

- “Great immediacy, in fact a teacher for everyone; one gets the interest and effort behind this whole system. An unprecedented and impressive effort”.

- “Any questions that come our way are solved directly”.

- “Better course structure, hierarchy of topics, communication with more questions and answers, convenience of time, moving around in your personal space, lack of formality”.

- “Saving time, you have the ability to calmly think about troubleshooting problems, under the guidance of the teacher”.

Below we present some of the disadvantages of the online discovery/constructivistic learning approach that combines synchronous communication and cognitive tools, compared to traditional teaching, as stated by students:

- “It takes a lot of free time to deal with Mathematica, since it is difficult to handle as it has several commands unknown to us”.

- “Human contact is absent. There can be no e-learning without the classic classroom. It is an excellent complement to the lesson in the classroom”.

- “It would be very useful to have an introductory lesson on the concepts of the program we used, not because of its difficulty, but for small practical topics that will make it more useful for students and not delay in time-wasting details. This would further increase interest as there would be no practical problems with using the program”.

- “It’s hard for all students to participate”.

V. CONCLUSIONS

This paper analyzed online discovery/constructivistic learning approach using computers as cognitive tools, focusing on the combination of synchronous communication tools and electronic worksheets in the environment of a cognitive tool. Moreover, the paper presents research results from a case study concerning the application of the approach at the Department of Statistics and Insurance Sciences of the University of Piraeus, focusing on students’ attitudes towards the approach.

The statistical analysis of the students’ answers showed that the students expressed positive attitudes to almost all questions regarding the LMS system used (GUNet E-Class), the cognitive tool used (Mathematica) and the online discovery/costructivist learning approach using electronic worksheets.

Regarding the LMS system, answers were almost equally distributed between positive and negative attitudes, slightly towards positive attitudes, only to the question whether the students can use the LMS system independently of the online presence of the teacher. Regarding the cognitive tool, answers were equally distributed between positive and neutral attitudes only to the question regarding the help browser of the tool.

The majority of the students were divided into positive and negative attitudes (with equal percentages) regarding whether they believe that online learning with synchronous communication substitutes sufficiently classroom instruction.

The total of students had positive attitudes regarding whether they would choose to attend another course with asynchronous communication (communication not at real-time), another course with online synchronous communication (real-time communication) and another course using cognitive tools with similar functions.

The innovative part of this paper is the combination of cognitive tools that traditionally are used at the settings of a computer laboratory on campus with online synchronous communication tools, in designing discovery/constructivistic learning activities for higher Mathematics’ Education. The results of this paper’s case study can be used in the identification of students’ attitudes towards the online discovery/constructivistic learning approach using cognitive tools and the identification of the benefits/advantages and disadvantages of the tools and the approach used as stated by the students that participated; yet the results cannot be generalized since the sample’s size is small and the sample was voluntary.

The author’s future directions include the combination of qualitative and quantitative research methods in evaluating students’ attitudes towards online discovery/constructivistic learning approach using cognitive tools using a larger sample, in order for the results to be generalized; also the combination of multivariate statistics’ methods in identifying factors that influence students’ attitudes and groups of students with similar attitudes.
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