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Generic Skills in Engineering Mathematics through Blended Learning: A Mathematical Thinking Approach*

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Generic skills are such an important requirement for successful engineers that their development in undergraduate courses is deemed essential. This paper summarizes the design of a blended learning environment based on mathematical thinking and creative problem solving aimed at improving generic mathematics skills in a group of undergraduate engineering students. The main goal of this study is to identify the effectiveness of the designed blended learning mathematics course on engineering students' generic skills. Results indicated that the blended learning engineering mathematics course has a positive effect on students' communication, problem solving and technological skills. However, the scores for both pre- and post-test for students' teamwork skills remained virtually the same. Some students' responses to the mathematics problems and journal writing describing their struggle, progress and growth encountered in the research implementation are also presented.

Keywords: blended learning; communication; creative problem solving; engineering mathematics; generic skills; mathematical thinking; teamwork; technology

1. Introduction

Various studies have shown that the context of engineering education has changed [1–3]. Current trends in technology and our increasingly complex workplace and society require engineers, if they want to succeed, to have a greater variety of capabilities, skills, and a wider understanding of engineering as a discipline [4–6]. Educational and enterprise managers as well as the industrial sector agree that a large number of engineering students graduate without generic skills, such as effective communication, teamwork and the ability to solve problems [7–10]. In the other words, graduate engineering students need skills and abilities other than those relating to their field of study [6, 8, 11–14]. Engineers need a new set of skills that not only encompass basic mathematics and science skills, but appropriate generic skills as well.

Hoddinott and Young [8] identified the following as generic skills required by engineers: (i) Basic skills, (ii) Team working skills, (iii) Thinking skills, (iv) Problem solving skills, (v) Personal qualities, (vi) Technological skills, (vii) Information management skills, (viii) Entrepreneurship skills, (ix) Leadership skills, and (x) Lifelong learning skills. The lack of effective generic skills can be related to the engineering curriculum [3, 15–18]. The rapid change of technology in society has not produced a corresponding change in engineering education and the same material is basically taught with the same tools and methods that have been used for many years [19–21]. Lumsdaine and Lumsdaine [22–23] noted that traditional teaching styles applied in engineering schools do not encourage whole brain thinking. The limitations of traditional teaching and learning styles may not only be responsible for engineering students' weakness in generic skills, such as communication, teamwork, and problem solving but may also be responsible for many of the problems that engineering students encounter in learning mathematics.

Mathematics is a prime constituent of the education of engineering students in many fields. Mathematics is offered as a prerequisite course for other advanced mathematics or even engineering courses. For engineering students, a knowledge of mathematics provides them with ways to work with several mathematical ideas and various representations and also can be used in their fields of engineering [24]. A lack of conceptual understanding in mathematics may hinder their understanding of other concepts or even whole subjects. In other words, mathematics enables engineering students to learn and apply a wide range of mathematical techniques and skills in their engineering classes and later in their professional work [25]. However, for most engineering students, mathematics is one of the most difficult courses in their field [26–27]. Many of the learning difficulties and mathematical deficiencies of engineering undergraduates have been well documented [26–30].

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Studies on student learning have found various methods that can support students in learning mathematics and generic skills. Researchers endeavor to support students learning mathematics by promoting mathematical thinking with or without the aid of a computer. There is quite an extensive study on promoting mathematical thinking in mathematics, such as in work by Tall [31–34] and Roselainy [35]. Tall used special mathematics software and a programming language in research to support student learning basic calculus, methods that are difficult to use in a formal class. In a study of multivariable calculus, Roselainy and her colleagues [24, 35–36] presented a model of active learning in a face-to-face (F2F) multivariable calculus classroom. The model was based on invoking students' mathematical thinking powers, supporting mathematical knowledge construction, and promoting generic skills, such as communication, teamwork and self-directed learning, but did not use computers.

The methods used by Tall and Roselainy and their colleagues did not employ the potential of the whole brain and thinking power to support the students' mathematical knowledge construction and generic skills. Even when these potentials were invoked, they do not make use of robust support tools. For example, all the methods used communication between student and teacher, but this communication was not supported by web communication facilities such as chat, e-mail and discussion boards, which can be used for synchronous (real time–different place) and asynchronous (different time–different place) communication. Moreover, in the case of multivariable calculus, Roselainy and her colleagues did not provide any computer facilities, such as animation, web-based tools or visual aids to lecturers to support the students' visualization.

Blended learning is an environment that combines online and F2F instruction [37]. There are many definitions [38–40] for blended learning but three common definitions are: (i) the combination of instructional delivery media [41–42], (ii) the combination of instructional methods [43–44] and (iii) the combination of online and F2F instruction [37, 45–46]. The first two positions reflect the debate on the influence of media versus method of learning. Both of these positions suffer from the problem that blended learning is so broadly defined [47–48]. The third position more accurately reflects the historical emergence of blended learning and is a combination of online and F2F instruction as defined by Reay [37, 45–46].

Creative Problem Solving (CPS) is a multi-step method for solving problems in various disciplines that uses not only analytical, creative and critical thinking in the most appropriate sequence, but also uses computers as a component of blended learning [23, 49–53]. It is suggested that CPS, which employs different thinking skills and tools, can fundamentally improve the way that students learn and support their generic skills, such as communication, teamwork and problem solving [53–54]. In fact, CPS combines aspects of other approaches in solving engineering, science and mathematics problems [7, 19, 23, 55–59]. Lumsdaine and Lumsdaine [23] suggested a CPS framework in the teaching and learning of mathematics for engineering students. They describe CPS as having five distinct steps: (i) Problem Definition (understanding the problem), (ii) Idea Generation (generating innovative ideas by using divergent thinking), (iii) Creative Idea Evaluation (clarifying concepts and reaching practical ideas that can be implemented to solve the problem using convergent thinking), (iv) Idea Judgment (selecting the effective idea or solution from among the best ideas), (v) Solution Implementation (examining all the consequences and finding a logical solution).

There has been very little research investigating the use of computers in the development and support of students' thinking powers in the construction of mathematical knowledge in multivariable calculus. Moreover, there has been little study concerning supporting effective communication, teamwork and problem solving in mathematics courses, specifically in multivariable calculus by CPS and computer tools. Thus, in this study, we introduce a model of teaching and learning engineering mathematics that enhances students' thinking and generic skills using computer-based mathematical thinking and a CPS approach. A blended learning environment is used as a sufficient environment to support engineering students' learning and generic skills. Specifically, this study identifies the effectiveness of designed blended learning mathematics courses on engineering students' generic skills, such as communication, teamwork, problem solving and technology skills.

2. Generic engineering skills

The workplace today is quite different from a few decades ago. Generic skills are becoming important requirements set by many stakeholders in order to produce excellent, competent and balanced graduate engineers [14]. Employers of university graduates frequently comment on the need for their recruits to possess abilities other than those relating to the academic or technical knowledge of the discipline that they studied as students [8]. Generic skills are buzzwords around universities these days and are much favored by government and employers [60]. However, searching for a common, appropriate definition of the widely used term 'generic skills' revealed that there was no consistent understanding of this term. Rather, many different definitions existed: Generic skills 'are communicative abilities enhancing efficiency in interactions' [61, p. 15], 'the ability to communicate and work in teams' [62], or 'is a sociological term for a person's Emotional Intelligence Quotient' [63]. The Association of Graduate Recruiters in the UK demonstrated that communication skills, the ability to work in a team, and problem solving were the important skills that employers looked for in graduates, along with their achievement in the traditional learning process in higher education [64].

Being able to work effectively in a team is an important generic skill for engineering students. Teamwork requires that the group must have direct and appropriate performance goals, clear deadlines, a suitable team based reward or assessment scheme, differentiated member roles, constructive conflict, appropriate expertise, training, and complementary skills, balanced planned composition and, finally, adequate resources and support [60, 65–67]. Although many programs today have made teamwork a fundamental elements of their curricula, research suggests that simply talking about or demonstrating the process does not aid the development of any skill; instead it would be better for the students to practice it themselves [68]. Consequently, students may not learn the skills necessary to perform effectively in a team environment.

Generic skills, such as communication skills, are required for an individual to be a successful team player [60]. Furthermore, communication skills enhance the employment prospects of students, their professional competence, their self-assurance and their ability to learn [69]. The ability to communicate, both orally and in writing, is an essential part of an engineer's job. During the early years of their career, most practicing engineers are aware of the need to communicate with vendors, managers, customers, technicians and other engineers. Demands have been growing for universities and polytechnics to place greater emphasis on the teaching of communication skills [70]. In undergraduate courses that are mathematically and technically oriented, it is very difficult to find timetable space for the development of communication skills. Therefore, there is the question of whether universities are preparing engineering students with communication skills, which are every bit as important to their careers as their technical training [71].

Problem solving skills are important generic skills for engineers in different contexts. This means that engineering graduates must acquire the ability to identify, formulate and solve engineering problems. Problem solving is defined as the process used to obtain the best answer to an unknown. It can also be referred to as a decision that is subject to some limitations [72]. Engineers combine analytical tools, sketches and modeling when solving problems [23].

Technological developments have led to fundamental changes in support of generic skills, such as problem solving, teamwork and communication. A computer as a thinking tool can help students to solve problems [23]. A computer is also a considered a communications tool when it is used for e-mail, chat and discussion forums. Online team activities can support students to prepare for their future workplace [73]. However, there is an instructional challenge in the way that teamwork should be taught in a virtual environment as more students are now studying online. To assess the effectiveness of team work it is important to have the ability to observe team behaviors in real time and to evaluate how team members interact with one another in order to achieve a common goal [74].

Subjects or courses that are not related to engineering or science are often neglected in engineering curricula due to the lack of 'room' for additional courses [71]. So, subjects that emphasize essential skills such as problem solving, communication, and teamwork do not have any room in the engineering curriculum. Drummond *et al.* [75, p. 21] suggested that the integration of generic skills within the career-technical education curriculum is an important approach in order to develop skills within the curriculum. This may be the best way to support students' generic skills, such as problem solving, teamwork and communication, while studying engineering, science and mathematics subjects. The use of CPS is a way of supporting engineering students' generic skills in parallel with other subjects in their fields of study.

3. Blended learning mathematics model

Tall [76–77] refined the theory of building and testing conceptual structures of Skemp [78] and found that the computer provides an environment that nurtures new ways to build and test mathematical concepts by supporting all three modes of building and testing conceptual structures. In fact, the computer brings a new dimension into the *'didactic triangle'* model, including pupil, teacher and mathematics in the F2F learning environment. According to Tall [31, 76], there are now four components with new roles and relationships between students: the teachers, mathematics and the computer, forming a tetrahedral in a suitable learning environment.

In a further study, Tall [79] noted that there are not only three distinct types of mathematics worlds, there are in fact three significantly different worlds of mathematical thinking: *conceptual–embodied, proceptual–symbolic, axiomatic–formal*. In fact, Tall's theory of three worlds of mathematical thinking underlies the creation of the computer software that Tall called a *generic organizer*, which he used in his researches [31, 33–34, 76–77] to support students' mathematical constructions and to build an embodied approach to mathematical concepts. Designing a generic organizer requires the selection of an important foundational idea. Tall used the notion of the *cognitive root* as a cognitive unit that contained the seeds of cognitive expansion to formalize definitions and later theoretical development. Tall showed how *the notion of local straightness* (for rate of change/differentiation) and *area under the graph* (for cumulative growth/integration) can be cognitive roots in building an embodied understanding of the calculus.

In the study of multivariable calculus, Tall's theory relies on a flexible blend of embodiment and symbolism. As for the transition from one variable to two, two variables form one vector variable and the idea of local straightness becomes local flatness and the locally straight approach that is based on a blend of embodiment and formalism. However, Tall's research focused more on supporting students' mathematical thinking powers to construct mathematical content in basic calculus.

Using the generic organizer does not guarantee conceptual understanding and Tall [77, 80] reported some cognitive obstacles faced by students when using this organizer. Tall believed that the learner requires an external *organizing agent* in the shape of guidance from a teacher, textbook, or some other agent. In this way, Tall suggested that the combination of a human teacher and a computer environment can support students' mathematical knowledge construction and avoid misleading factors.

The definition of blended learning as a combination of F2F formats and web-based formats identified an environment that includes two important components of Tall's method: a generic organizer (computer) and an organizing agent (teacher) [81]. In fact, the blended learning environment has rich tools to extend Tall's approach in promoting mathematical thinking in multivariable calculus. Furthermore, the use of e-learning as an important element of blended learning provides sufficient tools to support students' generic skills. It is proposed that blended learning has the potential to improve Roselainy *et al.*'s model for supporting students in three aspects of learning.

There is very little in the literature to identify the components that are involved in the learning process of blended learning. According to Tall [31], computers bring a new dimension into the *'didactic triangle'* model. Albano [82] extended the *'didactic triangle'* model and gave the four vertices as the author, the teacher, the student and knowledge, with new roles and relations assigned to each, thereby changing the learning process in e-learning environments. Norazah and her colleagues [83], also based on Henry [84], hypothesized that the key elements of e-learning solutions are content, technology, service and strategy. Combining the main components of Tall [31] and Albano [82], the author, teacher, student, strategy, technology, and mathematics can be hypothesized as the components of blended learning [81].

In the didactic scheme in blended learning, the author as the creator of the mathematics course has to define and identify the role of each component. The relationship between students, the relationship between students and teacher, and the relationship of both with other components are the most important aspects of the didactic scheme in blended learning. The author, who can also be a teacher, prepares mathematics tasks and assessments using technology tools and pedagogical strategies such as communication, teamwork and problem solving. In fact, mathematics, technology and strategy are important recourses in designing a blended learning mathematics course [81].

A blended learning environment will give students the opportunity to benefit from both F2F and e-learning instruction. In this environment, the theoretical foundation on which the development of strategies for mathematical knowledge construction and the enhancement of students' mathematical thinking are based on the work of Tall [79]. Frameworks from Watson and Mason [85] and the works of Lumsdaine and Lumsdaine [23] were used to design classroom activities and tasks. The following aspects are given taking into consideration the development and implementation of blended learning in multivariable calculus courses [86].

1. *Classroom tasks*: The mathematical tasks to be used in the classroom were compiled on a website (see http://mathed.utm.my/math). The tasks were based on *prompts and questions* designed to direct and guide the students' awareness of the fundamentals of problem solving.
2. *Assessments*: Both summative and formative types of assessments including quizzes and tests; timely classroom feedback and written assignments in F2F and online formats were used in this method.

3. *Computer and web aide*: by using the Modular Object-Oriented Dynamic Learning Environment (Moodle) as a course management system [87], sufficient resources were prepared for use in the F2F class and in laboratory sessions (as online and offline). In this environment, students can access lecture notes, web-based interactive educational tools, animations, videos, forum modules, chat modules, journal modules, assignments, assessments, surveys and feedback. Use of the web environment helps students to study at home. In addition, it will also help students find out more information about content and questions, and to submit assignments, projects and laboratory reports.
4. *Strategies*: Designing prompts and questions are being used in order to initiate mathematical communication between students and lecturers. Furthermore, web communication facilities such as chat, e-mail and discussion boards can also support the students' oral and written communication. Moreover, group assignments and team presentations support not only the students' team work, but also encourage discussion and sharing of ideas among the students. Working in pairs, small groups, applying critical thinking to problem solving, students' own examples, carrying out assignments, reading and writing in the F2F and web environment are other strategies of this method. Figure 1 shows the model of blended learning mathematics that is used as a guide to classroom instruction [86].

Technology (computer and web aided) as an element of the blended learning model, which includes tools such as files, video, discussion forums, chat, journals, animation and examination systems, can support didactical methods such as lectures, discussion and assessments, which are used to teach mathematics. Thus, technology as a part of the blended learning model can also support the students' thinking and generic skills: in other words, designing tasks, assessments and web resources in a special way, based on strategies that can be supported by technology based on mathematical thinking and CPS. Specifically, students' generic skills can be supported by using sufficient e-learning tools as an important element of the blended learning model.

Online mathematical tools are a type of web resource that allows students to access authentic real time data and to simulate complex activities. In addition, a course discussion board is used to foster student–student and student–lecturer communication during the course, providing a collaborative and shared space for the global community. By presenting tasks online, the instructor provides students with the opportunity to explore, access, download and upload materials on the web. In yet another activity, students are directed to various links, which offer interactive practice on the concepts. This java based program allows students to understand mathematical concepts and to solve problems.

Encouraging students to talk, to listen, to read, to write and to reflect on their mathematical learning and problem solving would enhance their awareness of their own thinking, as well as their generic skills. Consequently, they are able to improve their understanding, gain new insights into problems and communicate their ideas in their own group in a mathematical manner. In this way, students became more responsible for their learning and learn to think for themselves.

The prompts and questions that were developed based on mathematical thinking were placed within the relevant problems so as to guide students in their thinking and to make explicit the processes and structures that they were learning. They also served as motivation to engage students' participation in activities and communication. An extract of an example used in teaching the definitions of two-variable functions as well as domain and range are shown below in Table 1.

CPS strategy was used in designing prompts and questions in order to support students' generic skills, such as communication, teamwork, problem solving and technology skills. For example, for a problem such as 'If g is a function of one variable,

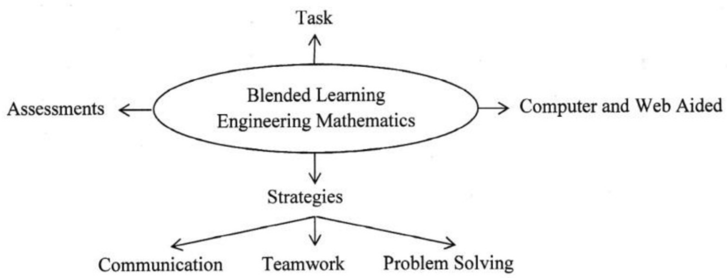

Fig. 1. Model of blended learning

Table 1. An example used to find domain, range and sketch a graph

Example:	**Questions and prompts**
Given $f(x, y) = 1 - x^2 - y^2$ i. Evaluate $f(2, 1)$, $f(-4, 3)$, $f(0, -5)$ and $f(u, v)$. ii. Find the domain and range. iii. Sketch the domain of f	• Which pair of variables are the input variables? • Which variable is the output variable? • Is there any restriction on the input variables for which the function is defined? • How do you represent the set of all inputs graphically?

how do you graph $f(x, y) = g(\sqrt{x^2 + y^2})$?'. The prompts and questions were as follows.

- Take specific function such as g_1, g_2 and g_3.
  - What is the similarity between them?
  - What is the difference between them?
- Sketch the graphs of $g_1(\sqrt{x^2 + y^2})$, $g_2(\sqrt{x^2 + y^2})$ and $g_3(\sqrt{x^2 + y^2})$.
  - What do you see in your pictures? Describe your pictures.
  - Compare the graphs.
  - What remains the same?
  - What has changed?
- Give other examples that can be sketched by computer.
  - What have you noticed about the graphs of the functions?
  - What patterns do you see in your answers?
  - Can the rule above be used to find the graph of $f(x, y) = g(\sqrt{x^2 + y^2})$?
  - Can you extend the rule to find the graph of $g(f(x, y))$ if $g(x)$ as a function of one variable?
  - Can you describe the characteristics of two-variable functions graphs that can be sketched by this rule?

4. Method

The nature of the research study calls for both quantitative and qualitative methods. A survey, students' written solutions and online journal modules were the most appropriate techniques to use to capture the essence of how the students' generic skills are supported. A survey requesting comments on our approach was administered to the students at the beginning and at the end of the first semester of the academic year 2012/13. However, most of the data were collected mainly through students' written solutions and online journal modules. Thus, cross data validity and confidence in the findings were achieved through data triangulation [88].

Of a class of 154 first year students enrolled in multivariable calculus at the Islamic Azad University of Kermanshah (IAUKSH) in Iran, 62 were randomly selected for this study. The respondents comprised 48 males and 14 females aged 18 to 21 from the fields of Civil Engineering, Computer Engineering, Electrical Engineering and Industrial Engineering. The multivariable calculus course offered by IAUKSH is a three credit undergraduate course and covers functions of several variables, partial derivatives, multiple integrals, vector functions and vector calculus. These topics were taught over a period of 14 weeks with three meeting hours per week, consisting of 2 hours F2F and a 1 hour laboratory session. In the lecture session, the mathematical concepts were introduced to the whole class. After the students had established a general idea of the concept, they then proceeded to the laboratory session, which featured online activities, the performance of interactive mathematics tasks, and the posting of messages and questions on the discussion board.

A survey comprising four sections was developed to assess the students' communication, teamwork, problem solving, and technology skills before and after the blended learning multivariable calculus course. All the students completed the questionnaires (see Appendix). The scale used to measure the students' generic skills taking into consideration effective classroom discussion in F2F and web was adopted from the literature review [17, 23, 89–92].

In the communication sub-scale, the summary items included: requesting help, finding information on the web, the willingness to speak openly, asking online questions, ease of asking questions, learning by classroom discussion, confidence, listening and respecting the ideas of others. Study with peers, sharing ideas with others, increased ability to solve problems, computing with others, relying on others to solve mathematics problems, finding errors, losing time, and helping teammates were the teamwork sub-scale items. In constructing the scales to measure the students' problem solving skills, the five problem solving steps through CPS from Lumsdaine and Lumsdaine [23] framework were considered. The statements assessed these components and the problem solving steps. Finding information from the web, not panicking if computer programs go wrong, confidence in mastering computer procedures, trusting oneself to get the right answer using a computer, handling mistakes, solving mathematics problems by searching the web, submitting assignments over the web, and downloading lecture notes from the web were the summary items in the sub-scale of effective use of technology. A 5-point Likert scale ranging from Strongly Disagree to Strongly Agree was used in the statements.

The pilot study was carried out at the Faculty of Engineering at IAUKSH at the beginning of the second semester of 2011/2012. The participants were 28 first year students in multivariable calculus who were selected using simple random sampling from among all multivariable calculus classes. The survey was distributed among students and the data were collected. Cronbach's alpha was used to determine the internal consistency of survey's reliability [93]. The closer Cronbach's alpha coefficient is to 1.0 indicates high consistency of the items in the scale. Cronbach's alpha coefficients for the communication sub-scale was 0.84, teamwork 0.76, problem solving 0.86 and technology 0.79. All of the constructs have reliability of more than 0.70, implying that all construct items are statistically reliable and none should be deleted. It is concluded that the reliability of the instrument is high [94]. To determine content validity, expert opinions were sought.

The null hypothesizes that are related to the research questions of this study indicated that there is no difference between the students' generic skills before and after experiencing the blended learning multivariable calculus course. In other words the median difference between pre- and post-test is zero. The Wilcoxon signed ranks test, which is the nonparametric version of the paired sample t-test used to test the change of repeated measures from one sample [95], was used to test the change in the students' responses to the generic skills scales before and after the course. The Statistical Package for Social Science (SPSS 16) was used to analyze the quantitative part of this study.

In this study, responses to two worksheet problems and four problems are analyzed in order to understand the effectiveness of the blended learning multivariable calculus course on students' written communication and problem solving. Moreover, based on students' responses to the worksheet problems, the impact of the course on students' teamwork and technology skills has been identified.

Worksheet problems were prepared and students had to solve them in groups. Each group consisted of 3–4 people, thus there were ten groups of three and eight groups of four students. Worksheet tasks were created using the framework provided by Lumsdaine and Lumsdaine [23] and prompts and questions were adapted from Watson and Mason [85]. The worksheets contained mathematical tasks that were designed to focus the students' attention on mathematical processes and structures in the various topics that they had to learn. Most importantly, the tasks required students to use various powers, such as specializing, generalizing, sorting and categorizing, conjecturing and convincing, while solving problems through CPS. The use of prompts and questions were to help make explicit the processes and structure of the mathematics and to provide students with the vocabulary to guide their own queries and thinking. Students were to solve worksheet problems by accessing computers and blended learning capabilities. Table 2 represents the first worksheet problem that the students were required to solve in their group in the laboratory session.

Table 3 shows the second problem worksheet. Because the function in this problem is in respect to y and z, the online tools cannot help the students solve the problem.

The main aim of the four problems was to understand students' abilities to solve problems based on mathematical thinking and CPS approaches. Secondary aims were to gain insight into how students wrote the solutions and communicated the solutions to one another. The four main problems were as follows.

1. Sketch the graph of the surfaces of $z = y^2$.
2. Find the limit if it exists $\lim\limits_{(x,y)\to(0,0)} \frac{xy^2}{x^2+y^4}$.
3. Given the integral $\int_0^1 \int_{\frac{1}{4}}^{1} f(x,y)\,dydx + \int_1^2 \int_{\frac{1}{4}}^{\frac{1}{x^2}} f(x,y)\,dydx$

Table 2. First problem worksheet

Vertical and horizontal shifts
Explore the results graphically of the transformation $g_1(x,y) = f(x,y) + c$, $g_2(x,y) = f(x+c,y)$, and $g_3(x, y+c)$. Describe what changes occur when the constant is added.
• Take a specific function g and sketch the graphs of the transformed functions g_1, g_2, and g_3 for different c. – What remains the same? – What has changed?
• Try a negative constant. – What is the same as before? – What is different?
• Try this for other examples and compare the results. – What remains the same? – What has changed? – What patterns do you see in your answers?
• Test your conjecture with other examples. – Can the above rule be used to find the graphs of the transformed functions?

Table 3. Second problem worksheet

Graphs of Functions of Two Variables
Sketch the graph of $f(y,z) = 9 - y^2 - z^2$.
By sketching the traces, sketch the graph of $h(y,z) = y^2 + z^2$.
How does using the graph of $h(y,z)$ help sketch the graph of $-h(y,z)$? Sketch it.
Compare the graphs of functions h and $-h$. • What remains the same? • What has changed?
By using the graph of $-h(y,z)$ how can you sketch the graph of $9 - h(y,z)$?
Sketch the graph of $f(y,z) = 9 - h(y,z)$.

(a) Sketch the region of integration.
(b) Write down the limits of integration if the order of integration is changed to *dxdy*.

4. Evaluate the integral $\int_0^1 \int_y^1 \sin(x^2)\, dxdy$ by reversing the order of integration.

Problem 1 includes an equation to test the students' ability to sketch the graph of a cylinder in R^3. The cylinder was denoted as $z = y^2$ terms of different variables that students had previously solved in class. The aim of Problem 2 was to understand if students knew if limits exist in two-variable functions at a point. Problem 3 involved sketching the region of integration in order to find the limits of integration should the order of integration change from *dydx* to *dxdy* Problem 3 was twofold: 1) to determine whether the students were able to sketch the region of integration based on the limits of both double integrals and 2) to show if the students know how to combine both regions and then to find the limit of integration if the order of integration is changed from *dydx* to *dxdy*. The aims of Problem 4 were to understand the students' ability to sketch the region of integration, find the limits of integrations, and use integral techniques.

Students were also requested to write an online journal module at the end of the blended learning multivariable calculus course to indicate their perceptions on the use of blended learning engineering mathematics. The actual number of students who responded to the journal module was 57 of 62 (92% response rate). The journal module was prepared in order to understand the effectiveness of the course on students' perceptions about generic skills. Students had to write about the effectiveness, advantages and disadvantages of using blended learning engineering mathematics to support their learning and generic skills such as communication, teamwork, problem solving, and technology skills.

5. Results

Student responses to the generic skill scales before and after treatment (see Appendix) revealed that a high proportion (69%) claim that they ask somebody for help when necessary. Only 11 students (18%) preferred to get information about the course from the web. Almost half (45%) had no desire to speak openly. There was an exceptionally high agreement (77%) on not asking questions about mathematics from the lecturer or peers through either e-mail or online chat. Furthermore, less than half (44%) thought that they should only seek help when they have a question. A high proportion (65%) also preferred to learn mathematics through classroom discussion with peers and lecturers. Lack of confidence when knowing that the instructor is observing them during discussion of the problem with their peers was a big problem for a great majority of the students (74%). Almost half (45%) believed in respecting the ideas of others.

As for detailed responses, it was found that a vast majority of students (77%) asked somebody for help only when necessary after the treatment. Slightly less than half (44%) preferred to get information about the course via the web. A considerable minority (38%) indicated that they did not have a desire to speak openly. However, a high proportion of students (61%) asked mathematics questions of the lecturer or peers through e-mail or online chat. More than half (55%) believed that it is easy to get help when they have a question. That might be the reason why a majority of students (69%) preferred to learn mathematics through classroom discussion with peers and lecturers. A high proportion (61%) also felt lack of confidence when the instructor was observing them during the discussion of the problem with their peers. Half (52%) believed that they have to listen to and respect the ideas of others. When using the 0.05 level of significance and a two-tailed test with significance (*p*-value) the Wilcoxon signed ranks test for communication skills revealed that $p < 0.05$ and the Wilcoxon signed ranks statistic, converted to a *z*-score, is equal to 6.62 ($z = 6.62$) (see Table 4). The effect size that determines the meaningfulness of the result [96] is 0.84 ($r = 0.84$).

At the beginning of the semester, a minority of the students (18%) preferred to study with peers in a group and only nine (15%) preferred to share their ideas with others. Four (6%) preferred to compute with others to solve the problem, while more than half (55%) believed that studying with peers was not advantageous. Almost half (50%) did not have any preferences for other items.

After the implementation of the blended learning multivariable calculus course, a considerable minority of students (37%) preferred to study with peers in a group. The majority (81%) did not like to share their ideas with others; however, half of them (52%) believed that working in team increased their ability to solve problems. Only eight students (13%) preferred to compute with others to solve a problem. These responses indicated that half of the students (50%) felt that they could rely on others in solving mathematics problems. In contrast, half (52%) believed that they could not help their group to find errors and mistakes. A quarter of the students (29%) believed that studying with peers was disadvantageous. However, more than half (56%) believed that they were able to help their teammates learn the course material. The results of the Wilcoxon test for team work skills before and after treatments revealed that *z* is equal to 1.661 ($z = 1.66$) with significance (*p*-value) equal to 0.097

(Table 4), and the effect size equal to 0.21 ($r = 0.21$).

Student responses to the problem solving subscale before the implementation of blended learning multivariable calculus course revealed that a high proportion (68%) knew how to get started on mathematics problems. However, a considerable minority (37%) believed that they could try different ideas if they were unable to solve the problem. Nearly a quarter of the students (24%) could develop a different hypothesis to solve the problem and more than quarter (29%) did not have any difficulties eliminating the hypothesis before solving the problems. A majority of the students (71%) believed that they could integrate their prior knowledge in solving the problem, while a high proportion (69%) could evaluate the information collected to solve the problem. Only eight students (13%) believed that they were able to judge how well the ideas could solve the problems. There was considerable agreement among the students (66%) that using a computer helped them in ensuring the correctness of the solution.

At the end of the semester, it was found that a vast majority of students (82%) knew how to get started on mathematics problems. More than half (58%) tried out different problem solving ideas and nearly half (48%) believed that they could develop a different hypothesis to solve the problem. Moreover, nearly half of the students (48%) did not have any difficulties in eliminating the hypothesis before solving the problems. There was an exceptionally high agreement among the students (79%) on the effectiveness of integrating their prior knowledge to solve the problem. In addition, the vast majority (76%) believed that they could evaluate the information collected to solve the problem. A high proportion (63%) were able to judge how well the ideas could solve the problems, while a majority (68%) believed that computers could help them in ensuring the correctness of the solution. The results of Wilcoxon test for problem solving skill revealed that $z = 5.71$ and $p < 0.05$ (Table 4) with an effect size equals to 0.72 ($r = 0.72$).

At the beginning of the semester, nearly half of the students (45%) believed that they could find the information using web searching tools and nearly a quarter of them (23%) had no fear of making mistakes when using a computer. Just over half of the students (53%) had the confidence to master the use of the computer procedure that was necessary for the course. This might be the reason why only seven students (11%) believed in their own ability to find the right answer by using a computer and 11 students (18%) believed they could correct their mistakes by using a computer. Near a quarter of them (24%) preferred to solve mathematics problem by searching for the particular problem on the web. A high proportion (63%) felt that it was convenient to submit their assignment through the web; however, only 11 students (18%) preferred to download lecture notes via the web.

After the implementation of the blended learning multivariable calculus course, a high proportion of students (68%) believed that they could find the desired information using web searching tools. Nearly a quarter (24%) had no fear of making mistakes when using a computer and a considerable minority of them (34%) were able to correct their mistakes using a computer. A high proportion of students (63%) had the confidence to master the computer procedures that were needed for the course. Only 12 students (19%) trusted their own ability to obtain the right answer using a computer. Slightly more than a quarter of the students (27%) preferred to solve mathematics problems by searching the web. However, for a vast majority of students (79%), submission of assignments through the web was easy, and half of them (50%) preferred to get lecture notes from the web. For technology skills, the Wilcoxon test results revealed that $z = 5.41$ and $p < 0.05$ (Table 4) with effect size 0.69 ($r = 0.69$).

Student responses to the worksheet problems revealed that students showed some progress in their ability to construct ideas on their own, to discuss problems with their friends and lecturers as well as communicate mathematically in class. The majority of the students solved the worksheet problems correctly in their own groups, solving the problems based on the CPS steps and mathematical thinking strategies. For example, in solving the first

Table 4. Wilcoxon Signed Ranks test for the generic skills

	Test statistics[b]			
	Post-communication – Pre-communication	**Post-teamwork – Pre-teamwork**	**Post-problem S – Pre-problem S**	**Post-technology – Pre-technology**
Z	–6.618[a]	–1.661[a]	–5.706[a]	–5.407[a]
Asymp. sig. (2-tailed)	0.000	0.097	0.000	0.000

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test.

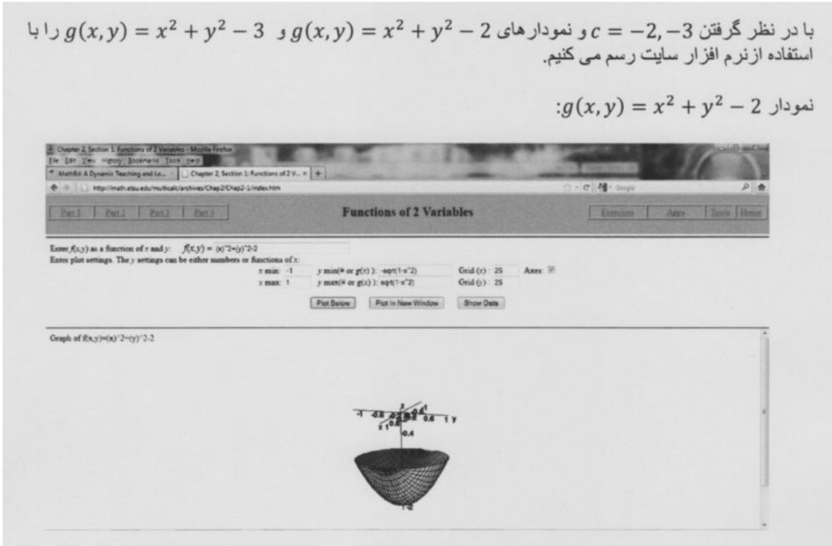

Fig. 2. A typical group's response to the first worksheet problem: the students explained that 'by considering $c = -2, -3$ we can sketch the graph of $f(x, y) = (x^2 + y^2) - 2$ and $f(x, y) = (x^2 + y^2) - 3$ using the online tools.'

worksheet problem, by examining different types of surfaces and sketching them using online tools on the one hand and finding similarities and differences through the CPS process on the other, they could find the vertical and horizontal shifts of $f(x, y)$ to $f(x, y) + c$, $f(x + c, y)$, and $f(x, y + c)$. Figure 2 represents the extracts of a typical group's solution process. These students responded to the question 'What is the same between them?' as 'the shape of the graphs have not changed, but both graphs shift vertically in a negative direction on the z-axis for negative units.'

Solving the different parts of the problems step by step via discussion and teamwork and making links among different parts of the solution helps students to solve the worksheet problems. For instance, in the second worksheet problem, using mathematical thinking strategies, such as similarity and difference as prompts and questions and also based on the CPS process, can help them solve the problem in their own group. These students could sketch the graph of $h(y, z) = y^2 + z^2$ and $-h(y, z) = -y^2 - z^2$ by first sketching the traces. Then, comparing the similarity and the differences in these graphs and the similarity between them with the single-variable function could help the students to conjecture and generalize by shifting the graph functions. As a result, they could sketch the graph $f(y, z) = 9 - y^2 - z^2$ by vertically shifting the graph $-h(y, z) = -y^2 - z^2$ by +9 units in a positive direction along the x-axis.

Forty-five students (73%) were able to solve Problem 1 on limits. In solving Problem 2, 43 students (68%) were successful. Figure 3 shows an excerpt of a student A's written work, indicating his efforts in making explicit his reasoning and response to the second problem asked. The student explained the problem solving steps and used 'we' for expiation which demonstrates his written communication skills. He wrote that 'first we sketch the region of integration for both integrals . . .' and by using the limits of the integrals they could sketch the region of integration for both integrals. Then, the student could find the new limits of integral when the order of integration was changed to $dxdy$ and wrote the integral as: $\int_{\frac{1}{4}}^{1} \int_{0}^{\frac{1}{\sqrt{y}}} f(x, y)\, dxdy$. The response revealed that this student relied more on the symbolic and embodied world of mathematics.

Forty-nine students (79%) were able to solve Problem 3. Students took different paths to the solution which showed that most of them knew

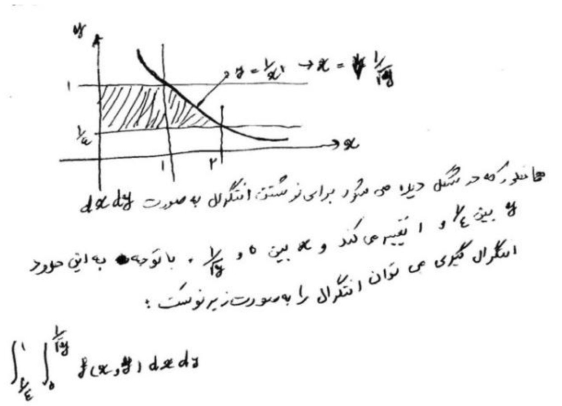

Fig. 3. Student A's attempt in solving Problem 2; the student wrote 'as can be seen in the graph to write the integral respect to $dxdy$ the x is changed between ¼ and 1 and the y is changed between 0 and $\frac{1}{\sqrt{y}}$. By considering this the integral can be written as: $\int_{\frac{1}{4}}^{1} \int_{0}^{\frac{1}{\sqrt{y}}} f(x, y)\, dxdy$.'

the condition of the existence of limit at a point. Most students (90%) could also solve Problem 4 correctly. Student responses in solving these problems revealed that students tried to explain the solutions using symbolic language.

Student responses to the online journal module revealed that 51 students (82%) believed that the blended learning mathematics environment could support them in learning multivariable calculus. Thirty-four (59%) believed that this method can support their communication skills. When asked about the effectiveness of the method a student noted that: 'The web course is a communication tool between lecturer and student, in which the lecturer can put all materials on the web and students can use them easily. In my opinion, using the web course and the lab sessions are good because I studied in a village and this course taught me to learn how to use online and offline computer tools.' Forty-two students (68%) noted the role of this method in support of their technology skills. Supporting students' problem solving through this method was mentioned by 24 students (39%). However, only 13 students (21%) believed that this method could support their teamwork skills. Another student's response indicated the effects of the method on student learning and generic skills as: '. . .the advantages of this method are that it allows us to be familiar with computer tools and help us learn things about the subject that may not be possible by using traditional methods. The method requires high Internet speed and is time consuming, which are disadvantages of this method . . .' Nine students (15%) also believed that low Internet speed and the time consumption of this method are the reasons that might prevent the implementation of this method in other subjects. These students also noted that low Internet speed resulted in difficulties downloading notes, uploading assignments, and using online computer tools.

6. Discussions

Students' responses to the communication sub-scale before and after the implementation of the blended learning multivariable calculus course revealed that the students have shown improvement on most items (see Appendix). However, the scores of the students' responses on item 3 about feeling the desire to speak openly did not improve for the majority of students. The Wilcoxon signed ranks test results ($z = 6.62$; $p < 0.05$) (Table 4) serve to reject the null hypothesis that there is a significant difference in overall communication skills between the pre- and post-test as a result of the students' participation in the blended learning multivariable calculus course. The effect size of 0.84 ($r = 0.84$) is large [97].

The null hypothesis tested in the blended learning multivariable calculus does not improve students' teamwork skills. Based on the Wilcoxon signed ranks test ($z = 1.66$; $p = 0.097$) (Table 4) the obtained value of z (–1.66) does not exceed the critical values of z which are –1.96 and +1.96 ($p > 0.05$); as a result, the null hypothesis cannot be rejected. According to Cohen [97], the effect size ($r = 0.21$) is also small. It means that the blended learning multivariable calculus has no effect on team working skills. A comparison of the students' responses to team work skills statements before and after the implementation of the course also revealed that students' opinion about all items did not improve much, except for items 10 and 15 (see Appendix). Student responses on sharing their ideas with others decreased strongly while their opinion of 'Studying with peers means losing', increased from almost half to a quarter of students.

Looking at the responses to the problem solving skills questionnaire before and after the course revealed that from a small minority, up to half of the students improved on items 18, 19 and 20 (see Appendix). Furthermore, the scores of the students' responses on items 17, 21, 22 and 23 were high. In other words, in the Problem Generation step, students' scores in problem solving skills increased from slightly low to slightly high. However, the items related to Idea Generation, Idea Evaluation, and Implementation of ideas had high scores. There was a high reversal in the indication of the students' belief that they were able to judge how well the ideas could solve the problems. Table 4 shows the significance level of Wilcoxon test. The $z = 5.71$, $p < 0.05$, and ($r = 0.72$) scores mean that the difference between the pre- and post-test was statistically significant at the 5% level.

The results ($z = 5.41, p < 0.05; r = 0.69$) revealed that there was a significant difference between students' technology skills before and after the blended learning multivariable calculus (see Table 4). A comparison of the students' responses before and after treatment revealed that the scores of all items of technology skills improved (see Appendix). Based on the responses to the items before and after the course, factors such as finding information from the web, having the confidence to master computer procedures needed for the course, submitting assignments and obtaining lecture notes from the web course showed significant improvement. However, the scores for items 26, 28, 29, and 30 did not increase much.

Findings revealed that the students used different mathematical thinking strategies such as specializing, conjecturing, completing, explaining, justifying and generalizing in solving worksheet problems that all of them worked out through oral and written prompts and questions. Furthermore student use of different modes of representation indicates that the blended learning multivariable calculus course supports the symbolic and the embodied worlds of mathematics or even sometimes the formal world of mathematics. It seems that designing prompts and questions to support and develop both symbolic and embodied worlds of mathematical thinking helps students to choose the appropriate world of mathematics and the transition from one world to other. Solving problems based on the multiple processes of CPS could also be seen in the students' solutions. Adopting CPS as a problem solving framework in the engineering subjects of mathematics not only helps students in solving problems but also supports their generic skills such as communication, teamwork and technology. When solving worksheet problems most students wrote about working as a team, and used 'we' in their responses. 'We sketched the graph' and 'We answered the questions' were common phrases in their answers. Most students were also able to use computer tools to solve worksheet problems. Using computer tools helped students to solve problems that are difficult when depending only on mathematical thinking and CPS strategies.

Students' written solutions to the problems also showed the effectiveness of the blended learning multivariable calculus course on students' learning. Most students could solve the problems correctly. The influence of the blended learning mathematics course on mathematical and written communication skills could be seen in the students' responses to the problems.

Based on the students' responses to the online journal module, most believed that teaching mathematics by blended learning is interesting, not boring, and is considered as a new experience for them, thus, it can support their learning. A majority of them also believed that this method helped them to take in the course easily. In their responses, the students also mentioned the specific skills that they had developed during solving problem in their groups. These skills included respecting one another, sharing ideas, and negotiating one problem solving process and answer to share with the whole class. However, some of them noted that the low Internet speed and time consumption were disadvantages of this method.

7. Conclusions

This study proposed the use of blended learning engineering mathematics to support students' learning and generic skills based on mathematical thinking and CPS. The diverse activities have motivated the students and has provided them with opportunities to take charge of their learning and generic skills. In this study, we achieved the aim of testing whether the designed model would be useful for students in terms of communication, team work, problem solving and technology skills.

The results of the pre- and the post-test confirmed that the blended learning multivariable calculus course positively affects students' communication skills. A statistically significant difference was found between the pre- and post-test level of communication skills. Most communication sub-scale items improved after the implementation of the blended learning multivariable calculus course. In the blended learning multivariable calculus course, the students' written and oral communications were supported by discussions between students and instructors based on different strategies, such as prompts and questions through CPS steps. Students' responses to the problems revealed that the students were actively supported in discussing, verbalizing and writing out their understanding of the mathematical ideas and concepts. The use of different technologies, such as a forums module, chat module, journal module and discussion boards, played important roles in supporting students' communication with each other and also with instructors.

The hypothesis that the blended learning multivariable calculus course affects students' teamwork skills was not supported by the results. Result revealed that most of the pre- and post-test scores remained virtually the same. In responding to the journal module, most students believed that this method supported their teamwork skills. In the blended learning multivariable calculus course, different strategies such as working in pairs and small groups based on CPS in the class were used in addition to worksheet problems, group assignments and presentations to support students' team work. Although the instructor used these strategies, it seems that the method was still not enough to support the students when working in teams.

The results rejected the null hypothesis as there is a significant difference between the students' problem solving skills before and after experiencing the blended learning multivariable calculus course. According to the students' responses to the journal module, adopting the problem solving framework based on CPS encourages the students to use their knowledge in solving problems. This method prepares the students for using CPS strategies in other subjects in their study field. Moreover, students can collaborate with each other and use technology tools to help them in problem solving.

The results revealed that students' technology skills increased significantly between the pre- and post- test. This indicates that the hypothesis that there is a significant difference between the students' technology skills before and after experiencing the blended learning multivariable calculus course is not supported by the results. Using computer tools to solve mathematics problems during the CPS process was the most important factor that supported students' technology skills. Student responses to the journal module revealed that this method not only helped them in the learning of multivariable calculus but also helped to familiarize them with new technology. As a limitation of the study, some students did not have access to high speed Internet, which made using this method rather difficult. However, many students expressed an interest in using this method for other subjects.

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Appendix

The pre- and post-test results of the generic skills statements

		Pre-test					Post-test				
Item	**Communication statements**	**SD**	**D**	**N**	**A**	**SA**	**SD**	**D**	**N**	**A**	**SA**
1	In my learning, I will ask somebody for help when necessary.	3	9	7	27	16	1	7	6	31	17
2	I prefer to get information about the course from the web.	3	29	19	3	8	3	15	17	16	11
3	I feel the desire to speak openly.	7	21	19	12	3	1	11	26	17	7
4	I sometimes ask the lecturer or peers a question about mathematics through e-mail or online chat.	28	20	8	5	1	3	9	12	29	9
5	I feel that it is easy to get help when I have a question.	5	4	26	20	7	2	5	21	26	8
6	I prefer to learn mathematics through classroom discussion with peers and lecturers.	13	27	7	10	5	3	5	11	35	8
7	I felt comfortable knowing the instructor is following us when discussing the problem with my peers.	25	21	8	8	0	5	10	9	26	12
8	I listen to, and respect, the ideas of others.	3	8	23	19	9	3	12	15	22	10

		Pre-test					Post-test				
Item	**Teamwork statements**	**SD**	**D**	**N**	**A**	**SA**	**SD**	**D**	**N**	**A**	**SA**
9	I prefer to study with peers in a group.	11	25	15	8	3	3	15	21	22	1
10	I like to share my ideas with others.	8	21	24	7	2	19	**31**	6	5	1
11	I believe that working in a team increases my ability to solve a problem.	2	9	34	15	2	**1**	9	**20**	**27**	**5**
12	I like to compute with others to solve a problem.	8	26	24	4	0	2	**23**	29	7	**1**
13	I feel that I can rely on others in solving mathematics problems.	2	14	33	11	2	**6**	**12**	**13**	**29**	2
14	I help the group find errors and/or mistakes.	3	18	31	10	0	**9**	**23**	**9**	**19**	**2**
15	Studying with peers means losing.	1	12	15	30	4	3	13	30	**15**	1
16	I am able to help my teammates learn the material in the course.	1	5	34	22	0	0	3	33	16	10

Item	Problem solving statements	Pre-test SD	D	N	A	SA	Post-test SD	D	N	A	SA
17	I usually know how to get started on mathematics problems.	4	2	14	29	13	4	0	7	36	15
18	If I cannot solve the problem, I keep trying different ideas.	5	12	22	17	6	1	11	14	23	13
19	I can develop different hypotheses to solve the problem.	11	21	15	7	8	9	9	14	23	7
20	I do not have any difficulties in eliminating the hypothesis before starting to solve the problems.	15	13	16	15	3	6	11	15	19	11
21	I can integrate my prior knowledge to solve a problem.	4	7	7	25	19	0	5	8	20	29
22	I can evaluate the collected information by myself to solve a problem.	2	4	13	29	14	2	3	10	28	19
23	I can judge how well the ideas could solve the problems.	16	26	12	4	4	10	11	2	20	19
24	A computer helps to make sure the solution is correct.	2	10	9	27	14	1	11	8	25	17

Item	Ability to use technology effectively statements	Pre-test SD	D	N	A	SA	Post-test SD	D	N	A	SA
25	I can find the information from the web searching tools.	3	9	22	23	5	2	6	15	22	17
26	If a computer program I am using goes wrong, I do not panic.	10	20	18	9	5	6	11	30	12	3
27	I am confident that I can master any computer procedure that is needed for my course.	5	3	21	25	8	3	1	19	27	12
28	I trust myself to get the right answer using a computer.	9	20	26	5	2	7	18	25	6	6
29	If I make a mistake when using a computer I am usually able to work out what to do for myself.	9	25	17	8	3	7	14	20	12	9
30	I want to solve mathematics problems by searching about them on the web.	7	12	28	11	4	2	12	31	12	5
31	It is easy to submit my assignment on the web.	4	9	9	27	12	2	4	7	31	18
32	I prefer to get lecture notes from the web.	12	18	21	7	4	8	10	13	24	7

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