Journal of Information Systems Education

Volume 30
Issue 4
Fall 2019

Invited Paper

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Recommended Citation: Matthee, M. & Turpin, M. (2019). Invited Paper: Teaching Critical Thinking, Problem Solving, and Design Thinking: Preparing IS Students for the Future. *Journal of Information Systems Education,* 30(4), 242-252.

Article Link: http://jise.org/Volume30/n4/JISEv30n4p242.html

Initial Submission: 3 May 2019
Accepted: 8 October 2019
Abstract Posted Online: n/a
Published: 12 December 2019

ISSN: 2574-3872 (Online) 1055-3096 (Print)

Teaching Critical Thinking, Problem Solving, and Design Thinking: Preparing IS Students for the Future

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ABSTRACT

Critical thinking and problem solving skills are included in the IS curriculum as foundational skills. IS education researchers recognize the importance of these skills for future IS practitioners given the complexity of the technology based society and economy of the future. However, there is limited work on how these skills are best taught in IS. This research reports on a course focusing on the explicit development of critical thinking and problem solving skills of first-year IS students at the University of Pretoria. The critical thinking part of the course focuses on the analysis, evaluation of, and response to arguments. Class discussions and assessments are based on local, authentic arguments. In the problem solving skills component of the course, students are taught to understand the nature of a problem and to classify it as belonging to one of three categories: puzzles, problems, and messes. For each category, appropriate problem solving approaches are suggested and practiced. To illustrate the role of design and creativity in problem solving, students have to create an artefact using the Maker Space of the university. They have to apply the five phases of design thinking as suggested by the Stanford d.school design thinking approach. The course has been presented since 2016, and feedback is collected from students annually. Based on a feedback questionnaire that the students complete at the end of each course, we have reason to believe that they find the course valuable and consider those skills to be applicable to other courses as well as elsewhere in their lives. They also point out the value it holds for their future as IS practitioners. As part of our ongoing research, we are investigating ways to develop a critical disposition amongst students, an important component of critical thinking.

Keywords: Critical thinking, Problem solving, Design thinking, Computing skills, Curriculum design & development

1. INTRODUCTION

In recent years, a number of Information Systems (IS) researchers pointed out the need to rethink the IS curriculum (Zhao and Zhao, 2010; Pratt, Keys, and Wirkus, 2014; Topi, 2019). Several reasons are given for this of which the dawning Fourth Industrial revolution and its effect on society and the future of jobs is seemingly the most critical one. The combination of powerful technologies and developments such as artificial intelligence, machine learning, biotechnology, 3D printers, and nanotechnology will lead to an unprecedented revolution in nearly every aspect of human life (WEF, 2018). World leaders, economists, and educationalists are scrambling to get to grips with the implication of this revolution on the future of jobs. Although IS is not primarily focused on the development of the technical component of the systems of this new era, Topi (2019) considers IS professionals to be ideally situated in bringing "the capabilities [of the technologies] together in a way that serves individual, organizational, and societal goals." While according to Topi, the core IS competencies will remain relevant, Pratt, Keys, and Wirkus (2014) argue for the alignment of the IS curriculum with liberal arts education outcomes. According to Pratt, Keys, and Wirkus (2014, p. 43), "a discipline-specific silo approach to curriculum design falls short of preparing the type of graduate needed in today's industry and society." What employers need are graduates with critical thinking skills, complex problem solving skills, good communication skills, and the ability to design responsible systems and consider ethical implications of systems (Pratt, Keys, and Wirkus, 2014). These skills are indeed included in the IS2010 undergraduate IS curriculum under the Foundational knowledge and skills category (Topi et al., 2010) and in the 2016 graduate IS curriculum as Individual Foundational Competencies (Topi et al., 2017), but Pratt, Keys, and Wirkus (2014) suggest a more explicit integration of these skills into the IS curriculum.

At the University of Pretoria, the Department of Informatics presents the only ABET-accredited IS undergraduate degree program in Africa. Every year, an average of 100, mostly South African, students enroll for the undergraduate degree in Business Information Systems (BIS). These students live in a multi-cultural, socio-economically unequal, and complex society. The quality of their schooling and economic reality differ substantially from one student to the next. This means that students enter the BIS degree program with vastly different levels of knowledge, skills, and resources. The fragile South

African democracy and economy can face the realities of the fourth industrial revolution only if its youth are equipped to take on the role of responsible, reflective citizens. Similar to Higher Education Institutions worldwide but even more so, South African universities realize the role it plays in educating such citizens. For example, included in the graduate attributes of the University of Pretoria is the following:

> They conceptualize issues and synthesize knowledge creatively to provide solutions for current and future-orientated challenges. They conduct context-focused, solution-orientated inquiries using critical, creative and logical thinking. They use a systems approach to manage change in complex situations, using global perspectives to improve understanding of causes and solutions related to local problems.

Indeed, the World Economic Forum (WEF) emphasizes the importance of problem solving and critical thinking as essential 21st century skills (WEF, 2018). It is acknowledged that critical thinking and problem solving are implicitly taught in the IS curriculum, but in support of Pratt, Keys, and Wirkus (2014), and given the South African context, the Department of Informatics decided to introduce a course for first-year IS students focusing explicitly on the development of critical thinking and problem solving skills.

The objective of this paper is therefore to give an overview of this course as well as students' reaction to it over the last three years. The next sections provide background on how critical thinking and problem solving skills are being taught after which we focus on IS education researchers' approaches to developing these skills. This is followed by an overview of and reflection on the course.

2. THE TEACHING OF CRITICAL THINKING

Tiruneh, Verburgh, and Elen (2014) define critical thinking as the ability to analyze and evaluate arguments according to their soundness and credibility, respond to arguments, and reach conclusions through deduction from given information. Halpern (1998, p. 450) gives a broader definition by considering critical thinking as the use "of cognitive skills or strategies that increase the probability of a desirable outcome." Halpern considers critical thinking skills as crucial in solving complex and ill-defined problems. A taxonomy of critical thinking skills as suggested by Halpern includes the following skills: 1) verbal reasoning skills, 2) argument analysis skills, 3) skills in thinking as hypothesis testing, 4) dealing with likelihood and uncertainties, and 5) decision making and problem solving skills. Problem solving skills in Halpern's writing refers to those skills used to judge the quality of a solution or decision, as well as the thought processes needed to reach the solution.

Researchers are in agreement that apart from cognitive skills, critical thinking (CT) requires a disposition towards being critical (e.g., begin open-minded, curious, truth-seeking) (Halpern, 1998; Tiruneh, Verburgh, and Elen, 2014; Abrami et al., 2015).

Although some researchers consider critical thinking skills to be domain-specific only (Abrami et al., 2015), the general assumption is that CT skills are cognitive skills which are domain-independent, distinct, and definable. CT teaching therefore involves the transfer of these skills to enable students to solve problems encountered in everyday life (Tiruneh, Verburgh, and Elen, 2014).

Tiruneh, Verburgh, and Elen (2014) studied the effectiveness of CT teaching interventions by considering literature on the topic published from 1995 to 2012. They considered interventions where CT skills were taught separately from, as well as included implicitly or explicitly within, the subject matter instruction. They label these two different approaches as direct teaching versus implicit teaching. From the literature, compared to implicit instruction, it appears that direct instruction of critical thinking skills results consistently in better critical thinking skills (especially in the case of first year students) (Tiruneh, Verburgh, and Elen, 2014).

Abrami et al. (2015) give a useful categorization of effective instructional approaches used in both direct and implicit approaches:

> Category 1: Individual study. This refers to students' individual work by engaging, reading, and solving problems on their own.
>
> Category 2: Dialogue. This refers to learning through discussion. There are numerous ways in which discussion can be facilitated. Some examples include a formal debate in class, whole-class discussion led by the teacher, group discussions, and student dyads.
>
> Category 3: Authentic or anchored instruction. The focus here is on presenting students with real problems or problems to which they can relate. Examples of relevant approaches include case studies, simulation, role-play, applied problem solving, and games.
>
> Category 4: Mentoring. This emphasizes one-on-one modeling of critical thinking disposition and skills by teachers or peers. From the meta-analysis on critical thinking strategies, Abrami et al. (2015) found that the most effective dialogue strategies are whole class discussion, teacher led group discussions, and teachers posing questions. Also, exposing students to authentic problems seems to be effective, particularly if applied problem solving or role-playing is used. Lastly, their research indicates that the combination of dialogue and authentic instruction is particularly effective, and even more so when combined with mentorship.

3. THE TEACHING OF PROBLEM SOLVING

The design and development of an information system is essentially a problem solving exercise (Turpin, Matthee, and Kruger, 2015). However, what does problem solving entail, and how is it taught?

According to Butterworth and Thwaites (2013), problem solving refers to the thinking and planning required to achieve a particular outcome. The less familiar one is with the problem context, the more thinking and planning are required. Turban, Aronson, and Liang (2004) define problem solving in a decision support system (DSS) context and state that problem solving entails a process that starts with an initial state and from there moves to search through a problem space in order to reach a desired goal. Turban, Aronson, and Liang (2004) regard problem solving and decision-making to be similar. Gammack, Hobbs, and Pigott (2011) believe that, in order to solve a problem, one needs to understand the nature of the problem first. This is in accordance with Pólya's (1957) four steps of solving a problem, namely: understand the problem, devise a plan or strategy, implement the plan, and reflect on the outcome. Gammack, Hobbs, and Pigott (2011) and Pidd (2003) believe that Ackoff's (1978) work on classifying problems as puzzles, problems, or messes is an essential departure point to solving problems. Ackoff (1978) classified problems in terms of their complexity. According to Ackoff, a puzzle is a situation where there is no ambiguity. There are clear rules to follow in order to arrive at a solution, there is only one solution, and, as with a jigsaw puzzle, it is possible to know that one has arrived at the correct answer (Pidd, 2003). Many problems in the field of mathematics can be classified as puzzles.

Problems are more complicated than puzzles since there are multiple possible solutions depending on the circumstances, the constraints, and the assumptions made. The field of operations research concerns itself with methods to address problems in a real-world context, such as vehicle scheduling and the placing of a new factory. Messes are to the opposite extreme of puzzles in that they are totally ill-structured. In messy situations, it is not even clear what the problem is that needs to be solved, let alone what process to follow. Messes are also known as wicked problems and are characterized by uncertainty, complexity, as well as multiple views on the situation by the various stakeholders (Rosenhead and Mingers, 2001). The field of study dedicated to resolving messes is known as "soft" operations research since it concerns itself with soft, people issues more so than hard, technical issues. It should be clear that problem solving in the IS field has to deal with the characteristics of puzzles (logical and analytical thinking), problems (socio-technical, open-ended real world systems), as well as messes (multiple role-players that may have incompatible perspectives). Indeed, many problem situations that appear like problems also have messy aspects (Pidd, 2003). This is why Gammack, Hobbs, and Pigott (2011) propose that in the field of IS, problem solving skills need to include dealing with puzzles, problems, as well as messes.

An aspect of problem solving that is not explicitly addressed in the body of work above is that of creativity. Evans (1992) argues that complex, real-world problems call for a larger solution space than what can be arrived at by analytical reasoning alone. He argues for the enlargement of the solution space by means of creativity (Evans, 1992, in Turpin, Matthee, and Kruger, 2015). Ackoff (1978) also holds that creativity is a key ingredient to problem solving. Gammack, Hobbs, and Pigott (2011) promote creativity as a means to provide different and new views on a problem situation. They believe it is a valuable skill in systems analysis and design.

Up to here, we have discussed important work that has been done on problem solving, taking into account the nature of problems and means to address different aspects of problems. Now, we will consider some previous work on the teaching of problem solving in the classroom. While little has been published on the teaching of problem solving in IS (see section 4), the topic has been more widely studied in the teaching of mathematics (e.g., English and Sriraman (2010)), engineering (e.g., Kimmel, Kimmel, and Deek (2003)), and computer programming (e.g., de Raadt, Watson, and Toleman (2006)). These fields have the analytical as well as design aspects of problem solving in common with IS.

As with the teaching of critical thinking, studies on teaching problem solving also concern themselves with the question of whether the material should be taught implicitly or explicitly. With an implicit approach, the assumption is that through the normal teaching of domain subjects, problem solving skills will emerge. However, "implicit instruction on solving a problem has been shown to result in poor learning outcomes" (de Raadt, Watson, and Toleman, 2006). Kimmel, Kimmel, and Deek (2003) note that while problem solving skills are acknowledged by engineering educators to be important, "unless it is included in the course objectives and specifically identified as a skill students are expected to master in the course, it is, at best, given perfunctory attention in the classroom" (2003, p. 810). The studies go further to say that students need to be taught specific strategies that link to specific classes of problems (English and Sriraman, 2010). There appears to be a consensus that the explicit teaching of problem solving is better, not just by recognizing problem solving as an explicit skill to be taught, but also by giving guidance in the form of specific problem solving methods and the problem situations to which these apply.

4. THE IS CURRICULUM, CRITICAL THINKING, AND PROBLEM SOLVING

The Foundational Knowledge and Skills category of the IS2010 curriculum includes the sub-theme "analytical and critical thinking, including creativity and ethical analysis." Problem solving is considered part of this category (Topi et al., 2010). It can be seen that some authors assume problem solving to be part of critical thinking, and others, critical thinking to be part of problem solving. Admittedly, to solve a problem, one needs comprehension and reasoning capabilities (Kimmel, Kimmel, and Deek, 2003) in order to understand the problem and reason through strategies. Comprehension and reasoning skills are part of the critical thinking skills set. To think critically, one needs an analytical mind set which in turn forms part of the ability to solve problems. According to Butterworth and Thwaites (2013), critical thinking is often associated with verbal texts, while problem-solving is usually associated with contexts that involve numbers or other mathematical language. However, the underlying thinking skills are "quite similar and certainly complementary" (Butterworth and Thwaites, 2013, p. 13). For the purpose of this paper (and the course on which we report), we regard critical thinking and problem solving as interdependent thinking skills.

Since the designing and building of information systems are always done to solve a problem, the assumption is that outcomes of an IS program will be analytical, critical, and creative thinking skills, whether taught in a formal way or not. Indeed, Agerfalk, Sjostrom, and Tuunanen (2017) go as far as using the California Critical Thinking test to evaluate the effectiveness of a new IS curriculum introduced after a merger between two universities. They found that the critical thinking skills of students improved because of the IS curriculum.

Considering the teaching of critical thinking and problem solving in the IS curriculum, almost no evidence could be found of direct instruction of these skills. The closest to direct teaching is where students are given a problem to solve and the solution is assessed according to rubrics based on the components of higher order thinking (e.g., analysis, evaluation, synthesis, and creativity). For example, Mukherjee (2004) promoted higher-order thinking skills in the teaching of decision support systems by asking students to analyse, evaluate, and respond to case studies on decision making. Similarly, Pratt, Keys, and Wirkus (2014) show how critical thinking can be developed by using a rubric based on critical thinking elements to assess all presentations across the IS courses. Other researchers focus on specific teaching strategies with the assumption that it will result in the development of higher-order thinking skills. Jones (2015) implements a BIS honors course based on Neumeier's metacognitive framework using high-impact teaching practices (collaborative learning, learning communities, and writing intensive exercises) and flipped classrooms. Saundage et al. (2016) use interactive visual narratives to teach business analytics to IS students and measure the effectiveness according to Bloom's higher-order thinking skills. In fact, implementing experiential learning (Riordan, Hine, and Smith, 2017), problem-based learning (Taipalus, Seppänen, and Pirhonen, 2018), game-based learning, and flipped classrooms (Caceffo, Gama, and Azevedo, 2018) in IS education are generally considered conducive for cultivating critical thinking and problem solving skills but are seldom implemented with that explicit objective.

The study by Steyn, Matthee, and Turpin (2013), although focusing on teaching creativity skills, was the only one to be found using a direct way of teaching these skills: creativity techniques (including de Bono's Six Hat technique, Do-IT, and brainstorming) were taught in a first-year system analysis and design course. Students had to use these methods in solving an authentic problem after which they had to produce a video to illustrate the way in which they used a creativity technique to reach a solution. Turpin, Matthee, and Kruger (2015) show that there is a lack of emphasis on fostering creative thinking skills in South African IS degree programs. Their findings show the importance of thorough domain knowledge and presenting authentic problems to students to foster creative thinking skills.

It is clear from the above discussion that IS educators are aware of the importance of the development of the foundational skills. However, the above studies are highly innovative, but mostly ad hoc interventions. The study by Pratt, Keys, and Wirkus (2014) is one exception. Pratt and colleagues went through a re-curriculation exercise to align course-level outcomes with university-level liberal education learning outcomes that include critical thinking and problem solving skills.

The Department of Informatics at the University of Pretoria went through a similar process, but it resulted in the identification of an extra course. In an attempt to address the unequal level of these crucial cognitive skills among the first-year IS students, and given the importance of these skills for the future, the department opted to develop a course through which these skills and aptitude are taught directly and explicitly.

5. THE COURSE

The semester-long course has been presented annually since 2016. Students are supported in their learning by a structured teaching and assessment plan that includes regular formative assessment and optional extra tutor classes. Summative assessment takes place through a written exam at the end of the semester. Through the study guide and regular communication via Blackboard technology, their educational pathway is communicated. The course consists of two parts: Critical Thinking and Problem Solving. Students attend two 50-minute lectures per week. Critical thinking as taught in this course entails the identification, analysis, and evaluation of arguments and responding with further argument. In the problem solving part of the course, students are exposed to different types of problems and problem solving techniques for structured and unstructured problems. Design thinking as a creative problem solving approach is also introduced to the students. Each sub-section is discussed in more detail below.

5.1 Critical Thinking

Seven weeks of the 14-week semester are used for this part of the syllabus. The study material is based on selected parts of the book by Butterworth and Thwaites (2013). Despite the diverse South African student group, we find the examples in the textbook sufficiently applicable to illustrate the principles. Table 1 presents the learning outcomes and objectives of the CT part of the course.

Learning Outcome	Learning Objectives
Understand what critical thinking entails	▪ Understand what is meant by thinking skills; ▪ Understand what is meant by critical thinking; and ▪ Understand why and when critical thinking is necessary.
Analyse an argument	▪ Understand what the different types of claims are; ▪ Judge a claim; ▪ Understand what an argument is; ▪ Know how to analyse an argument; ▪ Identify a conclusion; and ▪ Understand what diffuse conclusions are.
Critically evaluate an argument	▪ Understand what a flawed argument is; ▪ Know the different types of fallacies; ▪ Identify the flaws in arguments; and ▪ Understand how graphs and statistics are used in arguments.
Respond to an argument by developing further argument	▪ Develop a new line of argument with its own conclusion; ▪ Understand the use of counter-examples; and ▪ Anticipate counter arguments.

Table 1. Learning Outcomes and Objectives of the Critical Thinking Section

5.1.1 Instruction strategy. Using the terminology as suggested by Abrami et al. (2015), we make use extensively of dialogue: lecturers pose questions, lecturer-led whole-class discussions take place, and group discussions are encouraged. In addition, lecturers model critical thinking skills and aptitudes. The focus is also on authentic public discourses and problems. It makes a student relate to the problem at hand and, therefore, feel included. The importance of authentic content has been a finding of the authors' own previous research and supported by Abrami et al. (2015). One of the objectives of the course is to develop informed, engaged, and accountable citizens beyond the classroom context. The researchers, therefore, put a lot of effort into finding South African, context-specific examples for class exercises and assignments.

5.1.2 Assessment. The assessments include identification of arguments, analysis of arguments, identifying flaws in arguments, evaluating the credibility of an argument, and building further argument. As mentioned above, the focus is on arguments from authentic, relevant local content. A few examples of arguments used in assessments are given below (all adapted from articles in the popular press):

- By legalising rhino horn, rhino poaching will be curbed.
- The towing of icebergs from Antartica to Cape Town will solve the water crisis in Cape Town (in 2018, the city faced the possibility of running out of water due to a long term drought).
- The introduction of a sugar tax will not solve the obesity problem of South Africans.
- Race relations in South Africa are not as bad as everyone says (during the #FeesMustFall – the demand for free education – crisis at South African universities in 2016).

Arguments closer to the study field of IS:

- Artificial Intelligence can be our friend, despite the fears about its adverse effects on society.
- Business leaders, educators, and governments all need to be proactive in up-skilling and retraining people to prepare for the Fourth Industrial Revolution.

In addition, as an individual assignment in 2016, students had to argue how a self-driving car should be programmed to make a moral decision if faced with difficult choices.

5.2 Problem Solving

The other part of the course focuses on problem solving skills. To make sense of the vast set of such skills, the categorization of problems as suggested by Gammack, Hobbs, and Pigott (2011) is used. Problems are labeled according to their complexity: puzzles refer to well defined problems with specific solutions, while problems are partly structured with multiple possible solutions. The most complex type of problems are referred to as messes. Messes are unstructured and often not solvable. The best one can do is hope to get a better understanding of the problem and structure, and solve parts of it. In the course, approaches to solve each of these types of problems are introduced to students. In addition, design thinking (Hasso Plattner Institute of Design, n.d.) is introduced as a creative problem solving technique. One lecture is used to introduce students to a maker who explains the Maker Movement and what it entails. Students are then accompanied to the university's Maker Space where the assistants of the space explain what services and courses they provide. The Maker Space is a fun, colourful, and creative work space. The Maker Space houses technology such as 3D printers and programmable microchip kits, and it provides free training and assistance with these technologies. Table 2 gives an overview of the learning outcomes and objectives of this part of the course.

Learning Outcome	Learning Objectives
Identify basic problem types and problem solving approaches	▪ Understand how problems are defined and characterized; ▪ Differentiate between problems, symptoms and problem situations; ▪ Understand the difference between puzzles, problems and messes; and ▪ Be able to identify the appropriate methods to deal with puzzles, problems and messes.
Apply problem structuring methods to messy problems	▪ Understand the characteristics of a messy problem; ▪ Understand problem structuring methods; ▪ Understand Checkland's Soft Systems Methodology (SSM); and ▪ Apply CATWOE mnemonic to develop root definitions as part of the SSM process.
Apply design thinking to design an artefact	▪ Define design thinking; ▪ Contrast design thinking with problem-based thinking; ▪ Know the generic steps of a design thinking process; ▪ Identify the pitfalls of design thinking; and ▪ Apply design thinking by following the Stanford University's design thinking process to design and manufacture an artefact.

Table 2. Learning Outcomes and Objectives of the Problem Solving Part

Puzzles are taught by referring to problem solving strategies as proposed by Posamentier and Krulik (2015). These strategies include: pattern recognition, working backwards, adopting a different point of view, considering extreme cases, solving a simpler version, organizing the data, drawing/visual presentation, considering all possibilities, and informed guessing. Each of these strategies is illustrated with examples. Relating to problems (semi-structured problems), students are presented with decision analysis type problems where they are exposed to handling constraints, assumptions, and trade-offs. As an example, students have to consider their employment options after graduation and identify appropriate decision criteria for comparing these options. To deal with messes, Checkland's Soft System Methodology (SSM) (Checkland, 2000) is presented as a suitable approach.

5.2.1 Instruction strategy. Similar to the critical thinking part of the course, active class participation by students is encouraged. Also, lecturers model problem solving behavior. In addition, more emphasis is placed on group work in this part of the course. For example, the Jigsaw collaborative learning method (Doymus, 2008) is used when applying SSM. Messes typical to the South African context like youth unemployment are used in a class group assignment. The class is divided into stakeholder groups for the role-play (in the case of youth unemployment: the government, youth, private sector, and Department of Education). Each of these groups has to draw a rich picture of the problem situation and develop a root definition from their perspective by using the CATWOE mnemonic. Once this is done, students have to regroup into new groups consisting of at least one representative of each stakeholder group. Using the rich pictures and the root definitions developed during the previous round of the Jigsaw by the stakeholder groups, the new groups have to decide on a possible solution, create a conceptual diagram, and create a plan of action. This exercise clearly illustrates the contention that a mess cannot be solved, only better understood and managed. The instruction of design thinking relies heavily on project-based learning, as discussed in the next section.

5.2.2 Assessment. Different group assignments are used during the formative assessment. To establish an understanding of the different categories of problems, in a group, students have to identify the category to which a problem belongs (instead of solving it). When practicing strategies to solve puzzles, students are provided with a number of puzzles which they have to first solve and, second, identify the strategy that was used (e.g., pattern recognition). The approach to messes is illustrated by having a group assignment where students have to structure and understand a mess by using SSM (discussed above).

Lastly, project-based learning is used to illustrate design thinking. Student groups have to use design thinking (as a creative problem solving method) to design and build an artefact using the Maker Space of the university. Students use the Stanford d.school's approach to go through the design process and have to present evidence of this through a blog. The design approach consists of five phases: empathize, define, ideate, prototype, and test.

As preparation for the Maker Space group assignment, students are given the opportunity to practice the five design thinking steps by means of a class exercise. During this exercise, by going through the design phases, students have to use recycled material to create an artefact for a classmate to address a problem he/she experiences with accommodation. Over the past few years, students have created prototypes for study areas, multifunctional furniture, mechanisms to block noise, and apps to assist with time management, to name a few.

The artefact that has to be created using the Maker Space is limited by type, cost, and size. Examples of artefacts that had to be created over the past few years include a kitchen utensil, a corporate gift, a container, and an educational toy. Students have emerged with highly innovative artefacts. Two corporate gift prototypes resulting from this project are given below. Figure 1 shows a pencil holder that can be assembled and disassembled whereas Figure 2 is a mini candy dispenser. As can be seen in Figure 2, the base of the candy dispenser is 3D printed. The glass top is a recycled coffee jar that screws into the base.

The students can only complete the assignment by sourcing additional knowledge, and they are free to use any means to do so, including the internet and asking friends or family. In this way, students are prepared for the world of work where one is not given a recipe for completing a task. Further, the open-ended nature of this project serves as an enrichment opportunity for exceptional students.

Figure 1. Pencil Holder

Figure 2. Candy Dispenser

6. FEEDBACK

Since the start of the course, we asked for feedback on the different parts of the course. The feedback is mainly of a qualitative nature. A total of 292 students completed the questionnaire over the three years from 2016-2018. Ethics approval for collecting and disseminating student data was obtained from the university. Informed consent was received from the students who participated.

6.1 Feedback on the Critical Thinking Part

Only one open-ended question was asked about this part of the course: Please provide feedback about the critical thinking part of the course.

Fifty nine students mentioned that this part of the course helped them to start thinking critically. Thirty three students stated that they found it enjoyable. More importantly, students mentioned that enhanced critical thinking skills helped them to:

- Interpret and write narratives in use cases: "*The critical thinking part of the course was interesting and valuable to other modules such as INF171 [system analysis and design]. The extensive class assignments, activities and exercises also helped because they allowed me to fully understand the concepts.*" "*Critical thinking helps a lot, now that we are doing use cases in INF 171 it helps me think of what is being said, how it's being said and what I can take from this passage or rather case study I have been given.*"
- Interpret exam and test questions better: *"[Critical thinking] assisted with tests and assignments. Being able to break down a question or statement in order to understand what exactly is required from you as a student. It was very helpful.*"
- Prepare them for the future: "*It was really challenging but at the end of the day it equipped me with skills I can use in the near future; [Critical thinking] is an invaluable skill because in the line of informatics graduates, problems and situations are not always as they may appear.*"

6.2. Feedback on the Problem Solving Part
The questions on this part of the course include Likert scale questions as well as open-ended questions.

6.2.1 Feedback on problem categories and messy problems. Four Likert scale questions were asked on the problem strategy and SSM exercise part of the course. The scale was: 1) Strongly disagree, 2) Somewhat disagree, 3) Neither agree nor disagree, 4) Somewhat agree, and 5) Strongly agree. Each of the questions and the responses are given below.

Question 1: I found the theory lecture on approaches to address different kinds of problems valuable. Over the three years, 35% strongly agreed whereas 58% agreed somewhat. Figure 3 shows the comparison between the three years. Although it appears that more students agreed in 2018 that the theory lectures are valuable, the difference between the three years is not statistically significant.

Question 2: I found the class activities valuable where we had to apply strategies for problem solving, such as pattern recognition and visual representation. This question was only asked in 2018, and of the 132 students that responded, 37% strongly agreed with the statement and 52% somewhat agreed. It replaced a differently formulated question covering the same topic that was asked in 2016 and 2017.

Question 3: I found the theory lecture on messy problems and SSM valuable. Over the three years, 32% strongly agreed whereas 49% agreed somewhat. The comparison over the three years showed no significant difference.

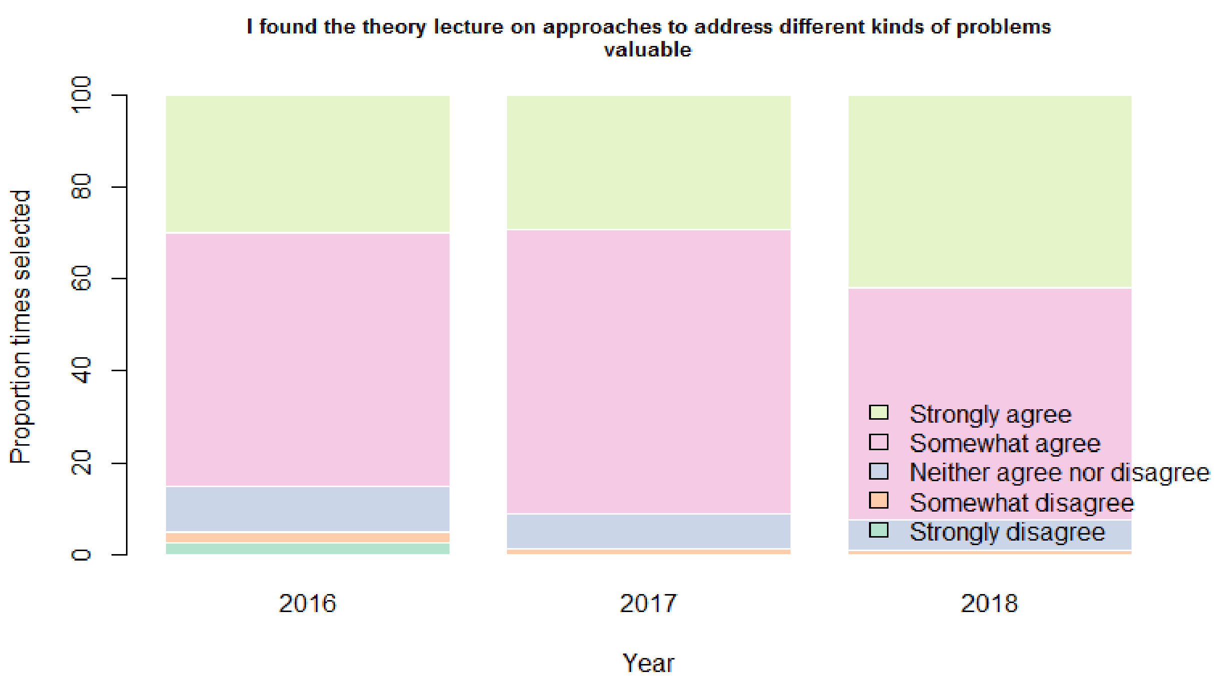

Figure 3. Comparing Frequencies of Responses to Question 1

Question 4: I found the practical SSM class assignment valuable. Over the three years, 36% strongly agreed whereas 48% agreed somewhat. Again no significant difference between the three groups was noted.

Aspect	Quotes
Transferability of skills	*"The problem solving and messy problems part was valuable and necessary because I won't only use what I have learned in class because it is knowledge I can use to solve any problem I might face in my life even after graduating"; "I found that helpful as a lot [of] the problems in our day to day lives as students aren't always ones we can solve systematically. Personally, I have made use of this method in my personal issues after learning and fully understanding "t"; "With regards to problem solving and messy problems helps us apply the problem solving methods inside and outside of our course"; "I think it was great learning experience to get to know how to classify problems, as this will allow me to know which problem is feasible for me to try and solve."*
Valuable to IS studies	*"I have learnt about types of problems and how to identify these problems, and how to identify practical and viable solutions for these problems. These skills are invaluable in the line of work which the BCom informatics degree prepares students for"; "The problem solving and messy problems part of the course is very interesting and it provides a building block for the Informatics subjects which is valuable."*
Important skills for the future	*"It was really interesting and would help people (including myself) solve problem in this unpredictable world of today."*
Addressing unequal schooling	*"Since problem solving skills are expected of a student to have developed through primary and secondary schooling, not all were given the same circumstances to be on equal plains; therefore, the abstract approach provided by the module and exposure to different kinds of problems allowed some, if not most, to further develop their level of problem solving skills"*

Table 3. Feedback on the Problem Solving Part of the Course

When adding up the percentages, it is clear that the feedback from the students is predominantly positive. However in the open ended question, "Please provide feedback about the problem solving and messy problems part of the course," some students mentioned the complex nature of the SSM and the difficulty they have understanding it. Other interesting aspects identified from the responses include the transferability of skills – a number of students mentioned that these problem solving skills are applicable to other subjects, everyday life, and their personal life as well. In addition, some students mentioned the value of these skills in mastering the material in their other BIS courses. Students also find these skills important for the future. One student considered the formal way of teaching problem solving as beneficial to the students with poor schooling (which was one of the reasons why we used this approach). Table 3 summarizes these aspects. Note that the student feedback in italics are in the students' own words, and no spelling or grammar corrections have been made.

6.2.2 Feedback on design thinking. Regarding the design thinking project, three Likert scale questions were asked. The scale used was: 1) Not at all useful, 2) Slightly useful, 3) Moderately useful, 4) Very useful, and 5) Extremely useful. The following responses were noted:

Question 5: How useful did you find the theory lecture and slides on design thinking? Over the three years, 24% found it extremely useful whereas 54% found it very useful. Again, no significant difference between the three years was noted.

Question 6: How useful did you find the class assignment where you had to design and build a prototype for student accommodation? Over the three years, 33% found it extremely useful whereas 33% found it very useful. A significant difference was found between the three groups. On closer inspection, the difference was between the 2016 and 2018 groups, but with the adjusted results, the difference is just above the significance cut off.

Question 7: How useful did you find the Maker Space group assignment? Over the three years, 40% found it extremely useful whereas 31% found it very useful. Again no significant difference between the three years was noted.

Open-ended questions were asked on each of the phases of the Stanford d.school design thinking methodology regarding their use of the Maker Space. It is evident that students used the Maker Space extensively in the prototyping phase while friends, parents, and other people in their social networks played an important role in the ideate phase.

Students also had to report on the influence of the Maker Space environment on their assignment. Apart from the services provided at the Maker Space, they found it conducive to creativity and describe the space as inspirational, exciting, and enjoyable. It also provided them a tangible way to test ideas and do prototyping. As one student put it: "it provides a platform for us to formulate our thoughts."

When asked to provide feedback about the design thinking part of the course, students picked up that the objective of this part of the course was to teach them creative problem solving: "It has made me feel like a problem solver, innovator, and felt like preparation for the working environment; it helped me come up with creative ways to solve problems." They also mentioned the transferability of the skills: "I did not know about the Design Thinking topic until it was taught to me in the INF 113 class. I do see myself applying Design Thinking in my future courses (e.g., programming courses) as well as my future endeavours." Another student stated:

> This provided different ways of looking at problems and ways of finding solutions. The Maker Space group assignment was a worthwhile experience because I was introduced to 3D printing and what actually goes into the design requirements. All in all, the entire assignment was a thought provoking experience. A lot of time and effort goes into satisfying a customer/client.

In a previous paper (Matthee, Turpin, and Kriel, 2017), we argue that exposure to the Maker Space and 3D printers gives students an idea of what it means to be part of the Maker Movement. Using the three components of the Maker Movement proposed by Halverson and Sheridan (2014), we provide evidence that some students understand that the action of *making an artefact* is at the core of the movement, that a *creative space* (communities of practice) enables the action, and that the community consists of *makers* (individuals that take on this identity). A number of students were eager to create their own artefacts using the Maker Space.

7. REFLECTION

The student feedback (Table 3 as well as section 6.2.2) clearly indicates the value that the students perceived to have gained from the explicit teaching of problem solving skills and specific problem solving strategies. This finding is in line with the literature where the explicit teaching of problem solving alongside with specific problem solving strategies was advocated (Kimmel, Kimmel, and Deek, 2003; de Raadt, Watson, and Toleman, 2006; English and Sriraman, 2010).

A lot of thought went into the improvement of the course over the years. For example, we introduced more interim deliverables in the design thinking Maker Space project to prevent last minute delays with long 3D print job queues. A section on misleading graphs and statistics was added to the critical thinking part of the course based on the book by Levitin (2016). This year, we added, as another problem solving approach, a lecture on computational thinking. Although all students in this course also take a programming course, we believe that the placing of computational thinking among other problem solving skills will improve the transferability of this skill to not only their programming course but also to other courses as well.

An important aspect of critical thinking that we do not address explicitly is the critical disposition. The only way we teach it is by modelling this behavior. More thought is needed on ways to address this shortcoming.

Up to now, the only evidence we have of the effectiveness of the course is the mainly qualitative, self-reported feedback we get from the questionnaires every year. The average marks of the groups are relatively high, and the pass rate is good (the pass rate was 89% in 2018). But what additional confirmation do we have that the students' critical and problem solving skills really improved because of this course? This year we will attempt to answer this question by administering a pre- and post-test to the students, hoping that this research will shed some light on the effectiveness of the course.

As researchers, we are interested in other related topics. For example, will students be in a better position to judge the credibility of online news (identify fake news) as a result of this course? Also, what is the relationship between meta-cognition and critical thinking skills, and what is the effect of a growth mind-set on critical thinking skills? These questions provide interesting avenues for future research.

8. CONCLUSION

This research describes a course presented to first-year IS students where critical thinking and problem solving skills are taught in a formal way. Preliminary qualitative results give us reason to believe that both planned and unexpected outcomes of the course are contributing towards the development of some of the IS professionals foundational skills – according to Topi et al. (2010, p. 369):

> IS professionals must have strong analytical and critical thinking skills to thrive in a competitive global environment. Students must, therefore, be problem solvers and critical thinkers and use systems concepts for understanding and framing problems.

In the survey that was run over the three years of teaching the course, a majority of students found the problem solving activities valuable for each activity on which feedback was requested. The qualitative feedback on the critical thinking component of the course shows evidence of students who were able to apply their newly gained argument analysis skills in other subjects as well as when completing tests and assignments. The feedback on the problem solving component also showed students who believed that their newly gained problem solving skills equipped them to better deal with problems presented elsewhere in their degree program as well as in everyday life. In the context of the socio-economically unequal background of the South African students, it was encouraging to hear from a student who believed that the problem solving skills assisted to address an unequal schooling background. In addition, feedback from the students points toward their perceived value of these skills for their future as IS practitioners.

In the context of the lack of studies reporting on the explicit teaching of the foundational skills of critical thinking and problem solving to IS students, this study makes a contribution. The study is limited by the self-reported nature of the feedback received from students. Future research includes aspects such as investigating the relationship between developing critical thinking and meta-cognition and better assessment of the effectiveness of our teaching with pre- and post-assessments.

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ISSN 2574-3872