Training Students to Successfully Solve Ill-Structured Problems in an Internet-Mediated Learning Environment

Kumar Laxman
University of Auckland

Abstract
Problem-based learning (PBL) is a pedagogical approach in which students learn about subject content matters in the context of solving a variety of different types of problems. David Jonassen in his design theory examines a typology of different kinds of problems that range from being well-structured to ill-structured. In this paper, we look at a research study on how students can be trained in the skills of digital information search literacy to be able to successfully solve ill-structured problems. Ill-structured problems are complex, multi-faceted and require deeper cognitive processing skills to be deconstructed and tackled. Given the pervasiveness of the Internet in schools as a repository of easily accessible electronic information, a training intervention framework based upon inquiry-oriented digital information search skills has been proposed and evaluated in this study to enable educators to methodically train their students to become effective ill-structured problem solvers.

Key words: Ill-structured problem solving, Internet literacy, information processing

INTRODUCTION
Problem-based learning (PBL) has in recent times aroused keen curiosity due to its pedagogical orientation of facilitating students’ active construction of knowledge. As a curriculum model, it is designed based upon the solving of either simulated or real-life problems. Inherent complexity and difficulty in the task design of the problems given to students could also be varied in bringing students through a continuum of diverse learning experiences that optimise their intellectual capabilities. Problem solving also empowers students to become independent, self-directed learners who autonomously steer their own learning progress and determine their desired learning outcomes.

Jonassen (1997; 2000) in his design theory examines a typology of different kinds of problems that range from being well-structured to ill-structured. Well-structured problems present all the limited elements of the problem; engage a bounded number of rules,
principles and concepts organised in predictive and prescriptive manners. On the other hand, ill-structured problems are endowed with many alternative solutions, ambiguously defined with unclear goals, unspecified constraints, lack relevant information and multiple criteria for evaluating solutions. Ill-structured problems need to be approached from different and often conflicting perspectives and require learners to express their personal opinions or stances on the problem. Being more complex and emergent, ill-structured problems are more difficult for students to solve and require instructional scaffolding.

Given the pervasiveness of the Internet in schools as a readily accessible source of electronic information, the role of digital information search skills in facilitating the solving of complex ill-structured problems is explored in this paper.

AIMS OF STUDY
One of the main purposes of this study is to examine analytically the pedagogical structures embedded within ill-structured problems. The extent of structure and complexity of the ill-structured problem-solving task that was assigned to participant students will be studied. The nature of the problem as defined by the number of issues, functions and variables embedded in the problem will be investigated in relation to students’ expectations of the demands of engaging in problem-based learning. The multi-faceted, heuristic ways in which students approach problem solving and the cognitive tools they leverage upon in so doing will be analysed in-depth.

The study also explores the empirical validation of a proposed inquiry-based intervention framework that scaffolds the development of a repertoire of competent information seeking skills in students to facilitate ill-structured problem solving. Through the findings of this study, it is thus hoped that a set of heuristics could be established to link the efficacy of different Internet information searching strategies to the effective solving of multi-disciplinary, multi-dimensional ill-structured problems.

RESEARCH SITE AND SUBJECTS
The research site for this study is a polytechnic tertiary institution in Singapore that implemented problem-based learning (PBL) methodology for all curriculum subjects and at all academic levels of study. It was hoped that problem-based learning would enable students to think divergently and innovatively. Students are required to work in teams of five on a given PBL problem each day of the week for the different subject modules. Students are required to come to classroom lessons with their laptops equipped with wireless connectivity to access the Internet for information searching. The one-day-one problem solving structure allows students to learn new disciplinary content knowledge through a variety of problem solving strategies. The day is typically structured with three meetings that facilitate interactions between facilitator and student groups on solving the problem. At the third meeting, students in their groups are required to present and defend their solutions to the entire class. At the end of the class, students need to record their thoughts on learning achieved for the day in their electronic reflection journals. The
participant students in this study were from a class of 25 first-year students for the module of ‘cognitive processes and problem solving’ that the researcher facilitates. The students in the class ranged in ages from 17 to 19 and were an even mix of males and females.

**INQUIRY-BASED INFORMATION SEARCHING SKILLS INTERVENTION FRAMEWORK**
A skills-based training interventionist framework was conceptualised and implemented to determine the impact of different Internet information searching skills and strategies in enabling students to successfully solve ill-structured problems. The building blocks of this exploratory, analytical framework are largely predicated on the conceptual ideas of Eagleton, Guinee & Langlais (2003), Jakes, Pennington & Knodle (2002), Spink (2003) and Nachiamas & Gilad (2002). The framework serves as a flexible reference structure and consists of a suite of Internet information searching strategies that equip students with the necessary skills to enhance their ill-structured problem solving capabilities. The iterative nature of development of these information searching skills needs to be emphasised since these activities are not meant to be carried out in a rigid, linear order of sequencing. Linearity of thought and time are characteristics associated with static, closed systems (Weed, 1989). A heuristic model facilitating effective Internet navigation and information searching processes to support ill-structured problem solving inherently cannot support predictability, stability, constancy or linearity.

![Figure 1. Training interventionist framework schema](image-url)
Kumar Laxman

The design of this framework is primarily based upon an inquiry-based learning approach that calls upon a variety of critical skills such as logical reasoning and reflective thinking. Inquiry-based learning promotes learning experiences enabling the exploration of theoretical ideas and conceptual change (Teixeira-Dias, De Jesus, de Souza, & Watts, 2005). The investigative questions posed by students help the students in organising their ideas, identifying and reflecting upon the various strands of information research.

The first skill articulated in the training developmental framework is for students to methodically learn about the various types of information search tools found in the Internet. The two key categories of Internet search tools that were explored during the training were search engines and search directories. Having acquainted students with the search tools offered by the Internet, Internet information search strategies and techniques that facilitate efficient information seeking were then taught to students. Some of the strategies that were explored were: Using multiple search engines, including metasearch engines to search for information, direct keyword search, wide search definition, use of Boolean operators etc. (Nachias & Gilad, 2002). The third stage of the intervention training involved acquainting students with framing essential and foundation questions. Jakes et al. (2002) have elaborated on the character of an essential question as one that requires students to make a viable decision or plan a course of action based upon sound reasoning. Essential questions are the starting point of a search attempt and they frame the search process. Foundation or subsidiary questions as the name suggests, provide students with the scaffolding structures to achieve the search objectives of the essential question. The answers to foundation questions generate substantive information that then can be processed and integrated to build up coherent solutions in reply to the essential question (Jakes et al., 2002). After students had learnt to model the questioning process, the next and final stage in the intervention framework is the training of students to initiate an action plan to seek answers to the specified foundation questions. Students were taught the strategy of coming up with concept-maps to support their information searching efforts. Students were trained to efficiently develop keyword-category concept maps and carefully select a pool of relevant keywords. This prevents students from prematurely focusing on content acquisition or the final products to be submitted. Concept maps as graphical representations of knowledge comprise of concepts and the relationships between them (Novak & Gowin, 1984). Consisting of labeled nodes and links they are useful pedagogical devices that allow students to acquire knowledge quickly and in non-linear ways than that afforded by traditional teaching methods such as simple keyword listing (McNaught & Kennedy, 1997).

**DESCRIPTION OF ASSIGNED ILL-STRUCTURED PROBLEM**

The following ill-structured problem was used as the performance indicator in evaluating the efficacy of the intervention framework on students’ ill-structured problem solving cognition given to students:

*Candle in the Wind*

Analyse a candle and the various representative meanings associated with the candle to construct a better understanding of the significance of a candle.
This is primarily an ill-structured problem since it is designed to yield larger individual variability in problem solving strategies and solution outputs. What gives this problem its ill-structuredness are the multiple solution pathway options solvers face in identifying the essence of the problem, devising the goals, formulating possible solutions and choosing the best solution. Being less definable and more open-ended, solvers have to combine or recombine networks of cognitive schemas in response to the requirements of the problem, rather than merely retrieve and apply a single existing schema from memory. This problem requires engaging a varied range of analytical problem solving processes in constructing the problem space and generating possible solutions, in comparison with a problem belonging to the well-structured domain. There is no one constrained set of rules, principles and concepts that could be applied in cognitively modeling and solving this problem, with divergent or alternative solutions being valid. There are multiple criteria in the evaluation of solutions and reaching a consensual agreement on an acceptable set of solutions is not an easy task. Solving this problem necessitates that students consider different decision-making and justification mechanisms as well as use their epistemic cognition, values, attitudes, beliefs and prior knowledge. In addition, the solving process becomes problematised as students have to develop arguments by gathering evidence, expert opinions, and integrating or synthesising a gamut of perspectives to support their standpoints.

The terminal learning objectives for this lesson include enabling students to appreciate that we could use various aspects of analysis to make sense of situations. Students come to not only appreciate but apply the different components of analysis encompassing deconstructing a complicated situation into individual elements or themes, understanding the meaning and relationship between these individual elements and then integrating the meaning to make sense of the situation. Finally, students should be able to recognise that the analysis done in a particular situation or context would vary within this general framework, depending upon the objectives to be met. The purpose of analysis is to make inferences, i.e. to make explicit (stated) in one’s analysis what is implicit (unstated but suggested) in the object of analysis.

The enabling learning objectives to be met in facilitating students’ learning for this problem-solving session include training students to examine the candle from various facets or angles of inquiry and apply judiciously the relevant frameworks of analysis to better understand the individual facets. For example, a chemical analysis of the candle would involve understanding the various components that would make up a chemical analysis. Students should come to recognise how the individual components from a facet of analysis relate with and mutually inform other facets in constructing layers of meanings and how they interact with one another to contribute holistic meanings to the whole. Thereafter, students would have to holistically integrate the meanings and relationships of the different components within a unifying archetype to derive the overall interpretation of that particular facet of the candle. Finally, students have to recognise that different forms of analysis employ different frameworks of research.
Some of the investigative learning issues embedded within this problem include scrutinising what a candle does, the ingredient materials that make up a candle, the purposes for which a candle is used and the spectrum of meanings associated with a candle. Students would also need to query on how an object or concept can be analysed and the procedures or processes related to such an analysis. Students would need to reflect on how the candle could be broken down into its various components for further examination and what steps need to be taken in interpretively making sense of the different facets of the candle. Students learn that the individual components and facets when put together afford deeper understanding of the candle, inclusive of its literal, metaphoric and symbolic representations. Taking into account multiple views in analysing the significance of the candle, students come to realise that these views are informed perspectives to be evaluated in assessing the values assigned to these perspectives.

**ANALYSIS OF STUDENTS’ SOLUTION PRESENTATIONS AND ARTIFACTS**

During their presentations and in their solution artifacts, students identified “What is a candle and what does it mean to us?” or closely-related variants as the essential questions that frame their knowledge research for this problem. Almost all the five teams of students mentioned the key issue of the origins of the candle as one relevant focal area of scrutiny that supports their conceptualisation of the problem space. Related foundation questions such as the following were raised: “What is the manufacturing process behind the making of candles and who first invented the candle?”, “How did the candle first come into existence and what were the underlying causes?”, “What is the recorded historical documentation on the candle?”, “What are the basic molecular units and chemical elements that make up the candle structure?” One of the groups wanted to investigate more on the physical and chemical properties of the candle, particularly those associated with the wax, whereas another team planned to research more on the necessity of the candle wick and how it impacts the burning of the candle. Another two groups of students were inquisitive to explore more on the wide array of colours/shapes that candles come in and the matrix of interpretive meanings conveyed by these colour/shape representations. These students were also keen in wanting to appropriate more information on the typology of candles and the characteristic traits that distinguish one type from the other. One group of students resourcefully wondered on the importance of candles and their applications within modern-day contexts where spaces are widely illuminated by either electricity or power generated lightings since candles, in comparison, occupy a rather antiquated position in our lives.

All five teams in the class performed credibly well in this ill-structured problem solving task and were able to successfully solve the problem and fulfill the learning goals of the lesson. The five teams had extensively applied the principles of effective information searching skills taught during the intervention training in seeking solutions to the given problem from multiple cognitive perspectives. This was expressively evident from the group presentations and the analysis of artifacts submitted by these students – all five teams had developed a protocol of guiding essential and foundation questions, based upon
which the students had structured their information seeking activities by constructing keyword concept category maps. These concept maps served as strategic scaffolding aids in enabling students to efficiently implement their search plans and accomplish problem solving. The high quality of products submitted by students, particularly the structures of the concept maps manifested the positive impact of the imparted training in improving students’ ill-structured problem solving mastery. All five teams listed the key essential question as “What is a candle and what does it represent to different people?”

The first group of students researched extensively the Internet for information on this problem theme and decided to systematically organise the information they had gathered within a two-tiered taxonomy comprising 5 broad classifications. This was a well-planned and coherent schema of knowledge codification consisting of a reasonable number of thematic categories. Students were thus able to explain and defend their solution in a structured and convincing manner. Students specified the following key foundation questions: “How did candles originate?”, “What are the different types of candles?”, “What are the different colours of a candle and their individual significances?”, “What are purposes or usages of candles?” and “What are the various shapes of candles and the meanings conveyed by them?” Hence, this team of students devised a concept map consisting of the five keyword groupings of shapes, colours, usage, types and history in framing their information research. Figure 2 encapsulates the main ideas produced by the students.

![Concept map of Candles](image)

**Figure 2.** The concept map of Team 1
The second group of students modeled a problem solving approach and solution plan quite similar to the first group’s but replaced the category of shapes with one on energy and temperature. This thematic category was derived from the foundation question of ‘What is the energy and temperature of the flame?’ However, surprisingly, no information on this category was furnished during the team presentation and content material on this category was again missing in the submitted solution product. This omission was highlighted to students and it was also pointed out that this category on energy and temperature seems neither cogent nor persuasive enough in terms of substantive relevance. The concept map representing this group of students’ information seeking roadmap is shown in Figure 3.

The third group of students decided upon a solution scheme that comprised only three crucial broad-based categories: uses, purposes and materials. The content in the first two classes of categorisation on uses and purposes was not distinguishably distinct from what the first two teams had presented, though the terminologies used in labeling the categories were different. Unlike the first two teams, this group of students had overlooked the vital topic on the various types of candles that could be differentiated by their colours and shapes. In addition, the ways in which these students had organised and presented their solution information output were not particularly well-sequenced. However, what gave them the added edge over the first two teams was their inclusion and detailed
explication of the category on materials. Spawning from the root foundation question of “What are the composite materials that make up a candle and their significance?”, other sub-topical questions such as “What are the chemicals in the candle”, “What is the role of wax and strings in the burning of a candle?” were generated by the students to enable a more expanded scope of analysis. Though, there was room for improvement in the information presentation, layout and structure of the solution submitted by this group of students, it was noteworthy that the information research that had been done was extensive and comprehensive. Branching off from the first layer involving the three essential categories, students had specified a number of related sub-topics in facilitating more in-depth investigations. The concept map embodying the main conceptual ideas of the third group of students is found in Figure 4.

The classification groupings developed by the last two groups of students in brainstorming, visualising, structuring and arranging their key ideas were, in essence,
similar to the previous three groups. The variations noted in their concept maps were minor and not very significant. The first three categories that both teams had formulated were akin to what the previous three groups of students had thought of in their analysis of the candle and its representations – materials/components, history and uses/purposes. The only difference was in the fourth category – one team defined its interpretation of candles in terms of the variegated types of candles whereas the other chose to examine the candle from the perspective of symbolism. The group of students who elucidated on the category of typology of candles did so in a distinguishable manner since their focus was on the varieties of candles, such as tealight candle, taper candle, beeswax candle etc. instead of colours and shapes, as was the prevailing focus of the other teams. The last group that concentrated on the symbolism of candles explored this aspect from multiple angles of inquiry involving different age representations, festivals, celebrations and cultural images. The foundation question that students had constructed that led to the creation of this category on symbols was “What do candles symbolise to different people?” Figure 5 and 6 are the two concept maps that depict the organisational structure of the ideas conceived by these two last groups of students:

![Concept Map](image)

**Figure 5.** The concept map of Team 4
Students who had included the category on the history of the candles in their conceptual frameworks explained that candle making is believed to have begun as early as 3000 BC. The first candles were developed by ancient Egyptians and Cretans and they served as the prime source of illumination. Candles were used to aid travelers in the dark, light homes and places of worship at nights. The earliest documented candles were made from various forms of tallow and natural fat whilst palm oil, coconut oil, beeswax and olive oil have also been used to produce candles. In the early 1800s, paraffin was made to replace tallow as the main ingredients in candle making.

For the category on materials used to make candles, students explicated that modern normal candles are usually made from wax, chemicals and string/wick. The wick is made of braided cotton and acts as the medium to burn the wax. Besides wax and wicks, fragrance oil and colour dyes are the other essential constituent ingredients of aroma coloured candles. Students mentioned that whilst modern candle-making processes vary, most candles are made through the timeless process of placing a cotton wick into wax which is then molded, dipped, extruded, pressed, rolled, drawn or filled into a desired shape and size.

On the aspects of colours of candles, students who had researched on this subject matter expounded that the various colours represented or conveyed layers of interpretive
meanings. Generally, it is widely accepted that white means purity, innocence, healing and sincerity; red represents strength, health, courage and passion whereas blue conveys a sense of deep emotion, harmony, joy, peace and truth. Green colour symbolises fertility, growth and balance, yellow expresses confidence, devotion, cheerfulness and charm whilst brown signifies endurance, neutrality and concentration. Pink colour communicates traits of morality, honour, romance and femininity, with black connoting morbid specters of death, sorrow and fatal endings. Interestingly, based upon individual perspectives, one group of students articulated the meanings they personally attached to candles. Candles denoted peace to one student while another student associated candles with hope. For the third student, candles embodied romantic notions and candles exemplified an outlook of unbridled joy to the last student.

The one group that analysed the different types of candles enumerated them as aromatherapy candles, beeswax candles, floating candles, jar candles, novelty candles, pillar candles, tape candles, tealight candles, wedding candles, scented candles and unity candles. This large spread of candle typology affirms the gamut of purposes for which candles are used nowadays. For example, floating candles are of utility as decorative accessories, cultural items (in Chinese lantern festivals) and tools aiding relaxation. Aromatherapy candles enhance “mood setting”, therapeutically soothe the nerves as well as alleviate undue stress and anxiety. In a similar vein, scented candles permeate the environment with lasting fragrances, physiologically promote healthier breathing and create an ambience imbued with ebullience. Unity candles are large ones used in wedding ceremonies and are elaborately designed to reflect the uniqueness of the wedding context by symbolising the blissful union of two special people.

All five teams explained substantially on the different uses and purposes of candles. This expansive category was generally broken up by students into several sub-components and dealt with individually in-depth. From the context of religious usages, students spoke about the universal centrality of candles in the methodologies of worship and ritualistic performances of diverse popular religions. Christians use candles as symbols in representing the light of God and invoking the grace of Christ. Candles were used to light up Christmas trees before the advent of electrical lights. In Christian traditions, advent candles which are different coloured candles are lit every evening throughout the month of December. For the Jewish people, lighting the eight candles of the menorah marks a significant commemoration of the resistance of the Jews against the Greeks and the re-dedication of the Temple in Jerusalem. In Judaism, candles are also used in remembering a departed, loved soul. For Hindus, candles play a vital role in their religious practices since candles represent the concept of Brahma or the aura of all-pervading cosmic divinity. During Diwali festivals, Hindus light up candles and oil lamps at homes to denote the victory of goodness over evil. In Buddhism, candles are widely used during the Ubon Ratchathani Candle Festival where candles are paraded through the city centre on floats accompanied by representatives of the respective institutions. In Humanism, candles
have become a symbol of the light of reason or rationality and in Wicca, candles signify the presence of the Gods and Goddesses.

Two groups of students touched on how candles, besides being the sole source of light in ancient days, were also the primary timekeeping devices. Candles designed for this purpose might have time measurements, usually in hours, marked along the wax. Alternatively, candle-clocks were produced such that weights could be attached to the sides of the candle and as the candle melted, the weights fell off and made a sharp noise upon falling into the bowl. The Sung dynasty in China (960-1279) employed this technique in monitoring the times of the day.

Other auxiliary practical applications of candles cited by students included candles as stylised works of arts, romantic emblems, spiritual communicational and developmental devices, fear and addiction conquering aids, ornamental artifacts and stress/health management enablers. One group even mentioned that for certain ethnic communities of people, candles are integral paraphernalia of their cultural/belief systems in beseeching supernatural forces to bless them with auspiciousness and prosperity. Another group dealt in depth on the functional character of candles as decorative pieces. The arrangement of candles impacts the styles of decoration and has been effectively used to add a more antiquated appeal or sense to the enveloping environment. Some place candles around the fireplace to give a dramatic backdrop and enhance the aesthetic attractiveness of the home. Interior designers have also recommended laying out candle lights in the garden or patio to transform these spaces into one of the most enchanting and endearing areas.

**REFLECTION JOURNAL ENTRIES**

In their learning journal reflections, students generally had favourable comments about the positive impact of the intervention training in enhancing their ill-structured problem solving performance. Some of the comments are as follows:

“I can easily say that these skills are essential to problem solving. I believe the skills helped us to easily complete the task and improve my competency in searching for information in the Internet. Coming up with the mind map enabled me to brainstorm for ideas before doing any research.”

“All the skills I have learnt have been very useful. I will be using these skills in my daily information searching activities. This is important knowledge I have gained.”

“Overall, these skills are vital. I am expecting to use them more in future to enable me to solve problems better and in my personal life as well. As information is necessary and we need to find it to solve problems, these skills will come in handy.”
CONCLUSION
In summary, a close examination of students’ solution presentations, scrutiny of students’ artifacts and analysis of students’ reflection journal responses for the ill-structured problem-solving session clearly reveal the nature and types of relationships existing between different Internet information searching skills/strategies and the structuredness of problem tasks.

Ill-structured or wicked problems are encountered in everyday and professional practice. There are no clear demarcations when it comes to defining the boundary contours of the problem space of these problems. These problems do not necessarily conform to specific content disciplinary domains and the problem solving processes cannot easily be conceptualised. Hence, ill-structured problems are structurally multi-disciplinary in focus (i.e straddling across multiple disciplinary fields of mastery) and their solutions neither predictable nor convergent. Both, elements of ill-structured problems and criteria for evaluating the efficacy of proposed solutions may not necessarily be known. These problems possess multiple or alternative solutions, goal states and pathways to deconstructing problems. The information requirements for solving ill-structured problems are complex, diverse, ill-defined, cross-disciplinary and extensive. The information searching that needs to be accomplished in approaching ill-structured problems is dynamic, expansive, multi-branched and rigorous. The research findings of this study inform that teaching students the two layers of digital information literacy skills embedded in the training intervention can help students to methodically structure and scaffold the diffused problem solving pathways involved in tackling ill-structured problems.

REFERENCES


Solving Ill-Structured Problems in an Internet-Mediated Learning Environment


