

THE ROLE OF ANALOGY IN KNOWLEDGE, COGNITION AND PROBLEM-BASED LEARNING

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ABSTRACT

This paper is aimed at examining how students make sense of and restructure causal phenomenon and ideas through analogies. While there exists various sense-making means, from developing theoretical concepts, formulating arguments to making connections between abstract thought and concrete application, learning in a problem-based environment yields another set of methods in which students are guided to construct their knowledge through engagement with problems. In particular, this paper will examine the ways in which learners make use of analogies or familiar situations to learn concepts and causal relationships and how they create an additional epistemological link through which knowledge can be gained. Problem triggers and writing samples from students' reflections about their learning and responses to test questions will be looked at to demonstrate the cognitive associations that are made between the concepts being learnt and the situations that they learn them through.

KEYWORDS

Problem-based learning, analogy, epistemology, cognition, concept learning, knowledge connections.

The motive for metaphor, according to Wallace Stevens, is a desire to associate, and finally to identify, the human mind with what goes on outside it, because the only joy you can have is in those rare moments when you feel that although we may know in part...we are also a part of what we know. (Frye, 2002, 224)

WHAT DOES IT MEAN TO LEARN AND KNOW SOMETHING?

This is a question that many philosophers, scientists and academics have asked for centuries. We are constantly trying to make sense of the world around us – both its tangible and abstract aspects. Through a system of formal education, teachers instruct and elucidate with the help of teaching resources (e.g. textbooks, lecture notes, laboratory experiments and task instructions) that organise ideas and phenomenon into logical, topical, sequential bits of ready-made knowledge that can aid learners in systematically managing new information. While such traditional teaching methods have been economically efficient in terms of information output, their effectiveness on long-term memory and transformative learning has not been as successful (Ramsden, 1992, 36).

In contrast, learning in a problem-based environment provides a cognitive and social space in which students are guided to construct their knowledge through engagement with problems. Instead of being told what they need to know, they define the learning issues stemming from a conceptual problem that is often displaced from its domain. For instance, learners might be introduced to the logic of computer programming not through a specific computer script, but through a children's game like "Rush Hour", in which players are required to manipulate toy vehicles through a traffic block. The concept is "signals for action" – which is the underlying logic behind how language components interact to express intended action, be it verb-tense structure in English or "if, then" instructions in Visual Basic code. The pervasive use of analogies to allow students to connect new content knowledge to situations that they are more familiar with would make for a deeper understanding of concepts and allow the learners to recall and use knowledge in more flexible ways.

It would thus be crucial to know how conceptual learning has taken place, and more importantly, how this can occur in students. This paper examines the dichotomy between knowledge as ideas and the expression of those ideas to allow for meaningful learning to occur. It argues that a complex cognitive process that involves analogical functions (e.g. metaphors, associations, inference, extrapolation and correspondence) is necessary for knowledge – in its abstract, ideological form – to be represented or constructed in a form that is contextually coherent to learners. The representation of learning in forms that are more familiar to learners creates an additional epistemological link where knowledge can be created:

Transforming knowledge means the continuous process of making and remaking ideas, to which the classroom explanation makes one series of contributions. Analogy and metaphor again play key roles here..." (Cornwell, 2004, 220)

Learners who are exposed to learning through analogies as opposed to domain-specific instruction would not only increase their ability to identify ideas across domains but would also gain a better understanding of the subject as knowledge is constructed upon their prior experiences.

THE PROBLEM-BASED LEARNING CONTEXT

The semiotics involved in designing learning situations to allow for such cognitive associations to take place will be discussed using Republic Polytechnic's problem-based learning (PBL) framework. It adopts a One-Day, One-Problem™ structure where students in classes of twenty-five work collaboratively in five teams to solve a problem posed to them at the start of the day. With the help of academic staff who perform the role of facilitators, student teams explore the learning scope of a problem, conduct research, discuss various approaches to the problem and finally consolidate their findings and resolutions to be presented to their class. Students routinely write reflections on their learning over the course of the day as part of their daily assessment. These reflections form part of the basis of the data that would assess the ability of students to learn through the use of analogies; the other set of data that will be examined will be how students respond to test questions that provide opportunities for analogical reasoning. Sample journal entries and assessment questions and student answers from the first-year G102 modules "Cognitive Processes and Problem-Solving Skills II"¹ will be examined and analysed for student preferences and abilities to transfer learning across domains and demonstrate higher-order cognitive processes.

DEEP LEARNING AND ANALOGICAL THINKING

Abstraction of meaning and an interpretation process aimed at understanding reality (Brockbank & McGill, 1998, 34) are higher order cognitive activities that promote deep learning. Deep learning happens when learners are able to extract and articulate principles from a specific learning context, and then construct their own conceptual models and frameworks for new contexts using these same principles. Surface learning, on the other hand, focuses on the discourse itself and on remembering, not internalising (Brockbank & McGill, 1998, 36). Analogies can help us to examine how deep learning actually happens by drawing meaningful and personalised connections between new and old experiences/ information so that we can reconstruct our understanding of concepts in our language, social and mental models. In other words, analogies are important mechanisms of "change in knowledge" (Gentner et al., 1997, 4) that drive and shape thought processes, allowing conceptual change and extensions to take place. The reverse is also true – using analogies to "teach" concepts allows learners to understand concepts in non-formal situations, so that they can extract their own principles of understanding.

There are many existing theories of analogy² ranging from computer simulations to scientific modelling, and it is not within the scope of this paper to examine or compare them. Our use of the term "analogy" focuses on the learner and how he makes cognitive sense of the semantic and causal interrelationship between an analogous form and its potential extensions:

A theory of analogy should acknowledge that "similarity" is a derivative notion, make explicit the basis of judgments of similarity and propose adequate criteria for these judgments. (Abrantes, 1999, 260)

In helping us articulate the process of analogical reasoning, we will be focusing on the following cognitive behaviours:

1. Identification of relevant prior knowledge in approaching a new problem situation.

2. Comparison of unfamiliar and familiar situations using similarities in causal relationships and semantic associations.
3. Ability to reason the congruency of comparisons through extrapolation of concepts or principles from the learning situations and demonstrating understanding of causal and semantic links.
4. Restructuring of understanding of new or extrapolated concepts/ principles by demonstrating awareness of both the usefulness and parameters (scope) of transference or application.

The cognitive processes outlined above will be examined in the context of problem scenarios, assessment rubrics and student responses to test questions. In terms of the data we are analysing, we will examine how the PBL context allows for the specific designing of learning situations to promote analogical thinking. This can happen at four levels:

- a) *Curricula-level* – where problem situations/ scenarios (triggers) with cognitive dissonance or gaps in sense-making happen, and where concepts or principles are not made apparent to learners. These triggers are often accompanied by worksheet questions where analogies are used to aid in cross-domain thinking.
- b) *Intervention-level* – where facilitative strategies to promote analogical reasoning (making sound connections, extension, explanation, application of knowledge to different contexts, critical analysis and evaluation etc.) are encouraged to help bridge learning gaps.
- c) *Social-level* – where collaborative opportunities that encourage the construction and negotiation of shared understanding takes place within a learning community (comprising members with diverse assumptions, backgrounds, mental models etc.).
- d) *Assessment-level* – where restructuring understanding through developing metacognitive skills (awareness of sense-making process) and demonstration of conceptual depth can be articulated and even measured via reflection journals, test answers etc.

This paper examines the use of analogy in greater detail at curricular and assessment levels, and briefly examines the facilitative and scaffolding processes involved in shaping analogical reasoning.

CURRICULA-LEVEL – PROBLEMS AS ANALOGIES

Problem scenarios or triggers in a PBL context offer excellent inter-disciplinary opportunities for analogies to be used for heuristic purposes, allowing learners to develop problem-solving abilities through conceptual engagement across domains. Many of our problem triggers are grounded in a scientific event or theory that is then extended, explored and explained beyond the scope of its original domain.

One example of engendering the dual learning objectives can be found in one of the G102 (Academic Year 2005/2006) module's problems on half-life and the use of analogical arguments. The problem made use of a video which showed two "alien" figures folding pieces of paper of different sizes into halves. The learning in this problem occurs on two levels – students first had to examine the concept of half-life and how it could be calculated, but that in itself was not the main point of the problem; links between the video and how students

came to understand the idea behind half-life better were also discussed during the problem. The appreciation of analogies through the use of an analogy not only gave students a first hand idea of how analogies function but also compelled them to engage with an unfamiliar concept through the use of the analogy.

Analogies are also used to scaffold the learning of students within the contexts of the problems. These scaffolds form part of the curriculum as they are included by the curriculum developers as key steps that a learner would make use of in order to understand and interpret the problem. One example comes from a problem from the G102 (Academic Year 2006/2007) module at Republic Polytechnic. The problem encouraged students to explore the atomistic ways in which knowledge has been created and how we can harness this to make sense of the world around us. One scaffolding question (in the form of a worksheet) made use of the idea of termites in a colony and how the different members of the colony perform different roles as atoms. The students were left to make the link between understanding the atomistic behaviour of termites with how knowledge can be created atomistically as well. Scaffolds that make use of analogies allow students to gain a better understanding of a more complex situation with a more familiar one. Atomism in this case is a very abstract concept that needed the analogical transfer to bring it to a level that can be easily comprehended and hence confronted for meaning-making to take place.

INTERVENTION-LEVEL – SCAFFOLDS FOR ANALOGICAL REASONING

In managing cognitive dissonance in the classroom, the facilitator often plays a pivotal role in bridging conceptual gaps through the use of analogies, rather than simply filling those gaps with information from the same domain. For example, in helping students understand how refraction works, the analogy of a marching band executing a turn might be more effective than explaining the physics behind density and light bending. This is because the analogy shared is familiar, visual and has a clear causal outcome to learners, i.e. the inner section of the marching needs to take smaller steps to navigate the physical space due to closer proximity compared to the outer section. The choice of analogy used is critical in helping learners not only appreciate the similarities in comparison, but also model for learners how analogical comparisons can be made and reasoned.

The facilitator role places the idea of learning on social and collaborative processes, where “prioritising involvement and connection, nurturing joint endeavours and stimulating the creativity of constructed knowledge...[can encourage] movement towards higher stages of learning” (Brockbank & McGill, 1998, 147). Because a variety of factors like social dynamics, prior knowledge, cultural backgrounds and personal experiences can affect classroom discourse, the facilitator needs to be attuned to different paradigms or frames of reference in helping his or her learners manage conceptual obstacles.

Further future research will examine analogies in classroom dialogue and discourse used by facilitators in Republic Polytechnic.

SOCIAL-LEVEL – SENSE-MAKING IN CLASSROOM

Republic Polytechnic's collaborative learning environment creates many opportunities for peer teaching to take place. Class profiles are typified by 16-19 year-old learners of mixed gender, race, culture and ability. Each class also has, on average, two foreign students out of a class size of twenty-five. While English remains the main medium of communication, students communicate meaning and attempt to bridge learning gaps using examples that they or their peers are familiar with. A student team that is able to elaborate their ideas with the use of an effective analogy would demonstrate deeper learning (Ramsden, 1992) of the topic at hand. Students who engage with materials purely on a surface level would not be able to effectively convert their learning into a useful analogy. The ability to make the leap to an effective analogy would entail an understanding of the nuances and complexities of the topic to be explained and an effective analogy can be correlated to effective learning as well.

An example can be found in a recent G102 (Academic Year 2006/2007) problem that focused on the difference between science and technology. One student team used an analogy of building sandcastles at the beach to explain its case. The team's argument was that science was akin to the discovery of the properties of wet sand and how it seems to be able to hold its shape even after it dries out. Science was explained to be all about discoveries and the pushing of boundaries of knowledge; technology, on the other hand, was likened to the creation and use of various shaped containers to build the sandcastles, and is thus more about the application and development of discoveries. The distinction was made clear through this sandcastle analogy and the students were judged to have arrived at a deep understanding of the difference between science and technology through their ability to explain it in the light of such an analogy. In contrast, students who provided mere definitions of the terms, or contextualised their meanings in isolation were deemed to have demonstrated surface learning.

Further future research will examine analogies in group discussions and presentations by students in Republic Polytechnic.

ASSESSMENT-LEVEL – MEASURING ANALOGICAL REASONING

In attempting to describe and measure levels of analogical reasoning abilities among the group of students taking the G101/G102 modules, we have adapted Gentner's idea behind "Structure Mapping Theory"³ (SMT) (1997, 5) to help define our parameters. SMT is based on the assumption that analogy involves a process of alignment and projection, where assertions in one domain are placed into correspondence with assertions in another domain, and further assertions are then inferred to be potentially true. However, the power of any analogy must have constraints for it to be successful:

For it to be cognitively plausible, a theory of analogical mapping must provide some natural limit to what will be inferred based on the mapping. It must also explain the fact that some analogies and some interpretations of a given analogy are preferred over others, even when no differences in factual accuracy are at stake. (Gentner et al., 1997, 5)

By mapping out what is considered to be "cognitively plausible" in the form of assessment rubrics, we have attempted to define the scope of accepted analogical projection in students' cognitive representation via learning journals and test answers.

An example of such a mode of assessment can be found in an Understanding Test⁴ for the G102 module (Academic Year 2006/2007). The question posed to students was:

People say lightning is electrical activity. Lightning usually occurs when static electricity builds up in clouds and gets discharged when it reaches a critical amount. Describe a similar situation that would allow you to explain such a phenomenon to others. Why is this a suitable situation to explain lightning?

The question was aimed at testing students' ability to explain an idea analogically, demonstrating the recognition of the necessary links that are made between the original situation to be explained and the analogy itself. A brief scientific background of lightning was given to remove the dependency of prior knowledge of this scientific phenomenon in their response. The marking rubrics (shown in Annex A) reflects this need as only the links between the analogy and lightning and the internal causal links are assessed. Sample answers are also included to show the variety of student responses and the range of levels of understanding that can be observed.

One possible criterion for measuring the value of an analogy is the extent to which it preserves interrelationships, causality and conceptual re-representation. Another is to compare how similar two analogous situations or descriptions are based on a defined "common essence" (Abrantes, 1999, 253) that both share.

The marking rubrics show this through the layering of the various levels of understanding that are implicit within the building of the metaphor. The 'essence' of the analogy in the question discussed lies in the slow build-up and sudden release of energy that leads to the bolts of lightning being formed. A good response would be able to show this essence while maintaining the internal causal links (i.e. how the build-up necessarily leads to a sudden release) that are also integral to the understanding of the essence. The good response (shown in Annex A) shows all this through the comparison to a person's rising temper. The weaker response lacks the demonstration of causality, with the inappropriate analogy of a filling of a pail, where the discharge of excess "energy" (water, in this case) is gradual rather than sudden. The highest level of analogical reasoning (explaining limitations or parameters of the analogy used), however, was largely absent in the data samples analysed. This could be due to a few reasons – the shortfalls of the test question and/ or the lack of impetus or opportunity for students to demonstrate such a level of analogical reasoning in their daily engagement with the curricula.

CONCLUSION

The use of analogies as a means of assessing understanding mirrors those of the curricula aims of analogies. Students who are able to apply and transfer their learning to explanations that make use of analogies would require a deeper understanding to tease out the causal links within the situation that needs to be explained (testing of understanding of content) as well as the understanding of how analogical reasoning can help in the demonstration of the said understanding (testing of process understanding). Using analogies as assessment tools can provide a deeper angle to which both formative and summative assessment can be conducted as understanding of both content and process skills within the curriculum. Further studies into

the use of analogies and how they aid in the cognitive development of student' understanding are detailed in Annex B.

Analogies not only help in the building of conceptual knowledge but are also instrumental in the assessment of this conceptual knowledge. Meaningful learning would occur through the engagement with the various forms of analogies that are both directly and indirectly related to the curriculum. The use of analogies can occur beyond the classroom and we would look towards the analysis of this in further research.

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¹ G101/G102 "Cognitive Processes and Problem-Solving Skills" are first year modules that scaffold students' learning in the PBL environment. They introduce students to the role of problems in learning, how concepts drive learning and how learners can thrive in this environment. The problem scenarios are often centred on scientific ideas or events.

² For a more thorough discussion of different theories and models of analogy, see Abrantes (1999).

³ It is important to clarify that Gentner's work focuses on computational implementations and analogical mapping as a syntactical function that assumes the prior existence of domain-specific structures and attributes. Our use of "analogical mapping" in this paper does not look at syntactical structures in the same way as her study did, but examines the semantic and causal relations in how meaning across domains is created through analogical reasoning.

⁴ There are no end-of-semester examinations in Republic Polytechnic and students are assessed summatively through a series of four Understanding Tests that occur at regular intervals during the semester. The tests for the "Cognitive Processes and Problem-Solving Skills" module are not content specific and are aimed at assessing the level of understanding of the various concepts and ideas encountered through the problems.

Sample Understanding Test question that makes use of analogies

Question:

People say lightning is electrical activity. Lightning usually occurs when static electricity builds up in clouds and gets discharged when it reaches a critical amount. Describe a similar situation that would allow you to explain such a phenomenon to others. Why is this a suitable situation to explain lightning?

Marking Rubrics:

	What to look out for	Examples
0 Marks	Irrelevant example or one that is too far removed from or too close to the example.	Lightning is like electrical current flowing through a circuit. OR Lightning is like a car that moves down the road smoothly and surely.
1 Mark	Description is valid but link to original situation is unclear.	Lightning is like a balloon that fills up with air that would make it burst after when it's too full.
2 Marks	Description is valid and the link to original situation is shown clearly (albeit implicitly). Recognises the build-up that leads to a discharge.	Lightning is like a volcano that builds up pressure until there is too much pressure which leads to an eruption. The eruption is a release of pressure that occurs once and would tend not to occur again till the pressure builds up again.
3 Marks (full score)	Identifies the link between the two situations and explains the effectiveness of the choice of analogy. Recognises the critical moment that leads to a sudden discharge.	The idea of the lava building up pressure in the cone of the volcano is analogous to the build up of charge within the volcano. The similar situation and the fact that the volcano only erupts when there is sufficient pressure is very similar to what happens in the clouds.

Sample Answers:

Good answer – full marks	Weak answer – 1-2 marks
<p>One similar situation is when a person is stressed, rationale behind is that stress building up within the person's psychological body is akin to the static that is building up in the clouds.</p> <p>When it static reaches a critical amount, it discharges from the clouds into the ground through lightning, which is full of energy and has the potential to be destructive.</p> <p>Similarly, when a person cannot withstand the stress levels anymore, they usually let it all out, through channels of emotion, or rather, better known as throwing tantrums, exhibiting violent acts until they feel better or tired, which means that they are out of energy.</p>	<p>This phenomenon can be explained in a different way so that other people would understand better. Imagine the lightning as water being poured into a pail, the water keeps filling up the pail but once it gets too full and reaches the brim, the water will overflow. Just like lightning, it'll strike when it builds up into a critical amount in the clouds.</p>

Analysis of student artefacts

Analysis of student artefacts (including test answers and reflective works) will be done through a set of codes developed to measure the various levels of cognitive skills that are necessary when using analogies. The four codes will be applied to similar sets of student works that are directly resultant from engagement with analogies (test questions that require the use of analogies or problems that make use of analogies to structure learning) as well as work that do not engage with analogies at all. The correlation between the understandings of students in both situations would be examined in future collection of data.

Code	Justification	Cognitive skill(s)
1. The analogy is relevant and appropriate to the situation that is to be explained.	<i>Looking at the direct relevance of the analogy. No questionable or implausible elements.</i>	Identification
2. The analogy shows clear internal causal links.	<i>The causes and effects of the situation to be explained are replicated accurately in the analogy. This occurs within the situation.</i>	Comparison using causal relationships
3. The analogy is thorough in its semantic and causal explanation of the whole situation.	<i>Analogy covers all the salient points of the situation that is to be identified and does not leave out key issues. Shows clear transfer of conceptual understanding to analogy.</i>	Extrapolation of concepts/principles Transfer of understanding
4. There is critical analysis of the use of the analogy.	<i>Recognition of usefulness and limitations of analogy.</i>	Meta-understanding

We will use a 4-point Likert scale – SD-D-A-SA (using the agree/disagree as it fits with the syntax of the different codes.) They map into a Very Low- Very-High for the various codes.
