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When Something Is like Something Else: Hands-on STEM through Analogies

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Abstract

ORT Israel schools have developed a unique framework for science and technology integrated studies. We use an innovative pedagogical method of ***learning by analogy****, where the students learn science and technology subjects by constantly drawing parallels between them, thereby minimizing, as far as possible, the discrete study of each field.*

The real advantage of this method emerges when the students are working actively to find for themselves new connections between different fields and ideas, rather than just absorbing specific examples of analogies. This way, "learning by analogy" leads to " ***thinking*** *by analogy", which in turn may yield innovative, inventive way of thinking.*

The highlight of learning by analogy at ORT Israel schools comes in the form of a yearly national competitive event. Once a year all 10th grade students of the Science & Engineering track convene for a two days science camp, taking its place at the Bloomfield Science Museum in Jerusalem. The students go through 30 different task stations all over the museum, and are challenged to solve science and technology riddles and puzzles using analogies. Each station exploits especially tailored combinations of one or more of the museum exhibits with props, pictures and texts, presenting interesting connections and analogies.

ORT Israel R&D center developed the competition framework as well as the content of these 30 original stations, creating a motivating learning platform that takes the advantageous but yet abstract notion of analogies and makes it concrete and physical. Over the course of four years, more than a thousand students had participated in these events, gaining a profound understanding of science and technology.

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1. Using analogies in STEM studies

1.1 Integrating different fields of study

The recent years in science education has followed the paradigms of science itself emphasizing the convergence of disciplines across the different fields of study. By breaking the virtual walls between disciplines, a multidisciplinary approach aims to enhance and broaden students' understanding while enabling them to gain a wider perspective of the physical world. This linkage between scientific fields and disciplines may be of the factors contributing to the growing popularity of STEM studies, which by integrating four subjects (Science, Technology, Engineering and Mathematics) seek to achieve greater value than the studying of each field separately.

For more than ten years, STEM studies are being taught at ORT Israel's secondary schools in the framework of the Science & Engineering track, designed for high achieving students interested in these fields. Beyond traditional STEM studies, efforts were made along the curricular development of this track to achieve an even more meaningful learning outcome through the use of **analogies**. Using analogies, the students learn STEM subjects by constantly drawing parallels **between** them. Thus, analogies enable teachers to **integrate** different STEM fields as opposed to the discrete study of each subject, eventually making STEM studies **inter**-disciplinary rather than **multi**-disciplinary.

Working with analogies is all about making connections. These connections can be made between (a) different concepts or (b) different phenomena.

a. In the first case, one has to identify a certain similarity between two seemingly unrelated scientific concepts; for example: rate and density (in a mechanical sense). One can hardly see a connection between a rate (or speed) of, let us say, a printer – which defines how many pages can be printed per minute; and a density of a gold nugget, which defines the mass of gold per unit volume. However, these two concepts are closely related, for they both represent the quotient, or ratio, between two other variables: printing rate is the ratio between number of pages and number of minutes; and density is the ratio between amount of matter (a somewhat slim definition but sufficient for our discussion) and volume of a body. Both rate and density can simply be expressed mathematically: A=B/C. Hence one can say that these two allegedly distant concepts are analogous to one another.

b. In the second case, one must find an identical pattern that exists within two different phenomena. Think of equilibrium, for example. It can be referred to a decisive tightrope walker in the circus, trying his best to cross over to the other side of the rope without performing an inglorious fall. It can also be referred to a once hot cup of coffee, not worthy anymore for drinking after being forgotten on the desk for an hour and reaching room temperature. And it can also be used to characterize the melting of the sugar that was being added to that same cup of coffee. We have a single pattern – expressing the concept of equilibrium – that governs phenomena from three different fields: a mechanical equilibrium of the tightrope walker, a thermodynamic equilibrium between the coffee and its surroundings, and a chemical equilibrium in the diffusion process of sugar. In physical terms we can say that all of these phenomena express the principle of minimum energy. Binding these phenomena together under the concept of equilibrium is what builds the analogy between them.

1.2 Pedagogical advantage

Learning by making connections between two different concepts, phenomena, systems etc. can yield a better and deeper understanding of STEM elements. This is especially true when one of the phenomena is already familiar to the students, while the other one is not. Creating an analogy makes it easier to recognize similarities and differences between the two phenomena. Paying attention to these differences may initiate a more meaningful learning in that it obliges the students to identify underlying mechanisms, and in general to activate higher order thinking skills. In learning by analogy, students are required to formulate generalizations about new concepts, identify common components and links between the phenomena, make inferences from one phenomenon about the other, analyze and organize information, ask questions and propose possible answers.
The basic assumption behind this pedagogical choice is that drawing parallels between different systems of concepts enables real, profound understanding:
"To grasp the meaning of a thing, an event, or a situation is to see it in its ***relations*** *to other things: to note how it operates or functions, what consequences follow from it, what causes it, what uses it can be put to."* (Dewey, 1933, p. 137)

2. The implementation of learning by analogy

2.1 Hands-on activity

In 2011 the authors of this paper took upon themselves to develop a two days seminar that will implement, hands-on, the method of learning by analogy. Bringing the students to work with analogies was a main pedagogical objective we had set for the seminar. But two additional social objectives were set: (a) to motivate the students which by then only took their first steps in the Science & Engineering track; and (b) to acquaint them with team work skills, as these fundamental skills will serve them on their work on engineering projects in the following years.
The result was a two days seminar with a variety of activities, amongst them a visit to the Israel Museum (an art museum), which was specially tailored for the group with focus on technological and design aspects of its artifacts; and a lecture given by an engineer on a relevant and exciting topic. However the highlight activity of the seminar was a challenging competition in the Bloomfield Science Museum in Jerusalem, in which 30 teams (4-5 students each) were competing each other in solving challenging riddles presented in stations across the museum. Each station utilized one or more of the museum exhibits, which were connected in some way to the riddle. The solutions varied from deciphering a riddle or a code, staging a picture, sketching a design or a scheme and building a model. In addition, all stations required a written answer. The students were asked to show their answers to one of the museum guides for evaluation. Also they were asked to take a photo of their product using their smartphones and send it to a digital data base. In total, each team had to follow a course of six stations. At the end of the competition the organizing team had summed up the scores (received digitally by the guides through their smartphones) and announced the winners.

2.2. Examples of stations

c. **Damping in mirrors and springs:** The station was located at the preschool ward of the museum, where a room of mirrors was located. After some priming tasks and questions about reflections and mirrors, the team was asked to pull and release a spring (not part of the exhibition but was placed there for this purpose). Then the team was asked to draw the analogy between the behavior of the spring over time and the fading reflections from two parallel mirrors. The analogy exercise led to the dumping phenomenon, causing the spring to stop from swinging and the reflections of the mirrors to fade away.
d. **Turing machines back and forth:** One of the exhibits in the science museum presents several paintings and some short musical pieces – some made by humans and some by computers. The students were first asked to separate the two kinds, and through this make acquaintance with the Turing test (enabling to distinguish between a human and a machine). Then the students had to explain the connection to the familiar CAPTCHA test commonly used in websites, and describe how it allowed only humans to proceed. Lastly, the students were asked to think of examples of a reverse Turing test, in which only machines were able to proceed (for instance a fax machine, producing sounds that only machines can identify and extract the information from, in contrast to humans). The analogical nature of this station was revealed in analyzing the Turing test, extracting its main principle (i.e. to tell computers and humans apart) and apply it in a new way.

2.3 Principles of hands-on analogy activity

Of the basis of experience gained, we extracted out understanding as to the rational and best practice of a good hands-on activity using analogies.

a. **Disruption:** At the core of a good activity lies some sort of disruption. We had both disrupted the museum by moving around exhibits and by creating an activity that asks something besides the obvious. This positive disruption generates original thinking.
b. **Locate shared principles:** As described above, one of the forms of learning by analogy is by inference from one phenomenon to another via shared principles. Start by locating these principles.
c. **The math of the matter:** A good way of finding relations between two phenomena is to look for a joint mathematical model. If the mathematical expression is of the same sort, an analogy can be formed.
d. **Gradual challenge:** Most of the stations were composed of a series of tasks and questions. The first ones were more basic, easy and leading, while the last questions or tasks of each station were the toughest. Scoring was in reverse order, so most points were given to the more basic tasks - in order to avoid frustrating the students.
e. **Team work:** Most stations required team work, either physically, intellectually or both. We also encouraged the teams to appoint a team registrar to keep track on the assignments and to put them in writing.
f. **The fun factor:** An important thing was to make sure that the teams were kept in good spirits. Many stations had an element of physical interaction with exhibits or with props, while others had a humorous dimension. Sounds of laughter and cries of wonder during the competition are a good indicator. Look for them!

3. Conclusion

In this article we have portrayed our experience in developing a hands-on activity for the Science & Engineering track. Our aim was to take the language of analogies, until then taught in classes mainly theoretically, and to teach it in a tangible and sweeping way. We set off with a basic concept of how to do it, and in the process of the past four years we have refined it and earned better understanding of what enables it to succeed and what is not.

During the four years of having this seminar, it appears to have taken an important role in the studies of the Science & Engineering track in ORT schools. Its influence is greater than the mere two days it takes place every year, as some of the teachers prepare their students before the seminar, and most of them continue to practice its materials after it is over. The teachers report that the seminar has a very positive effect on the motivation and team formation. It also has a positive effect on the understanding of the method of learning and thinking by analogy, as seen later in class.

These are, of course, sporadic reports. Further research is required on the impact of the seminar regarding the following aspects: (a) students' motivation and attitude towards the Science & Engineering track; (b) the acquirement of "thinking by analogy" skill.

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