



TEACHING STRATEGIES ENHANCING THE DEVELOPMENT OF SCIENTIFIC PROCESS SKILLS

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ABSTRACT

Scientific process skills are crucial to develop a comprehensive knowledge of science. They also enable students to apply a theoretical content into real life problems. My study examines the frequency of use of selected teaching strategies by the Diploma Programme (DP) science teachers. I also examined whether DP science teachers and students consider these strategies as useful in developing the scientific process skills. The quantitative research has shown a different perception of both groups, especially for PowerPoint presentations. In contrary to DP science teachers, students suggested that this tool can significantly enhance the development of scientific process skills. This idea has been a controversial and much disputed subject in recent literature. Nevertheless, DP students and science teachers concluded that in- and outdoor investigations may enhance the development of scientific process skills. Unfortunately, both teaching strategies are not the most frequently occurring in science lessons.

Keywords: Scientific Skills, Teaching Strategies, Process Skills, Discovery Learning.

1. Introduction

Science and teaching students about science should mean more than delivering scientific content. For many years students were required to memorize facts and build encyclopedic knowledge that in most cases has never been used in real world. As a results, a vast majority of students did not enjoy science lessons and perceived science subjects as being difficult and content-heavy. Science teachers have repeated similar teaching methods based on memorization and replications of teacher`s thinking process. A science teacher was treated as a first source of information and lecturing was widely used to explain scientific phenomena. Science was presented as a static collection of facts to be transmitted without understanding causes and processes. Fortunately, this approach and teaching techniques have been gradually vanishing from schools. It is currently understood that, in order for students to be successful in science they must possess scientific skills (Valentino 2000, Aktamis 2008 Chalufour 2010). Nevertheless, the educational researchers and practitioners noted a dissonance between the demands of real world scientific problem solving using a variety of skills and the current educational capacity to prepare effective problem solvers (Pavlo at al 2014). A considerable amount literature has been published on the importance of skills in science. Despite this, very few studies have investigated the impact of teaching strategies on the development of the scientific skills.

The effective science teaching needs to embrace knowledge and science processes and practices, as well as provide multiple opportunities for students to use these processes and apply them across many experiences (Chalufour 2010). This type of learning is known as discovery learning (Valentino 2000). Students who experienced the discovery learning are able to know, use and interpret scientific explanations as well as generate and evaluate scientific evidence (Duschl et al 2007). Moreover, they understand the nature and development of scientific knowledge and participate actively in scientific practices and discourse (Duschl et al 2007, Chalufour 2010). A large and growing body of literature has suggested that science should be a process of acquiring understanding, not just a collection of facts. It should emphasize the importance of student research as well as developing scientific skills (Duschl et al 2007, Chalufour 2010, Symes et al 2015).

While a variety of definitions of the term *scientific process skills* have been suggested, this paper will use the definition first suggested by Padilla (1990). The term scientific process skills has been popularized by the curriculum project ‘Science – a process approach’ (SAPA). Educational practitioners involved in the project concluded that the science process skills form the foundation needed to obtain more advanced skills. Drawing on an extensive range of sources, the researchers divided scientific process skills into the subskills:

- Observing
- Inferring
- Measuring
- Communicating
- Classifying
- Predicting

Other researchers concluded that scientific process skills are defined as abilities to observe, analyse, hypothesize, experiment, conclude, generalize and apply the theoretical information into practice (Aktamis 2008). According to Valentino (2000) science skills can be

categorized into three groups: process skills, reasoning skills and critical thinking skills. The process skills are defined as '*skills used to gather information about the world. Reasoning skills help to understand the gathered information*'. Lastly, critical thinking skills '*require students to apply information in new situations*'. More complex definitions of scientific skills have been developed by Bybee (2008) who grouped them into acquisitive, organizational, creative, manipulative and communicative skills.

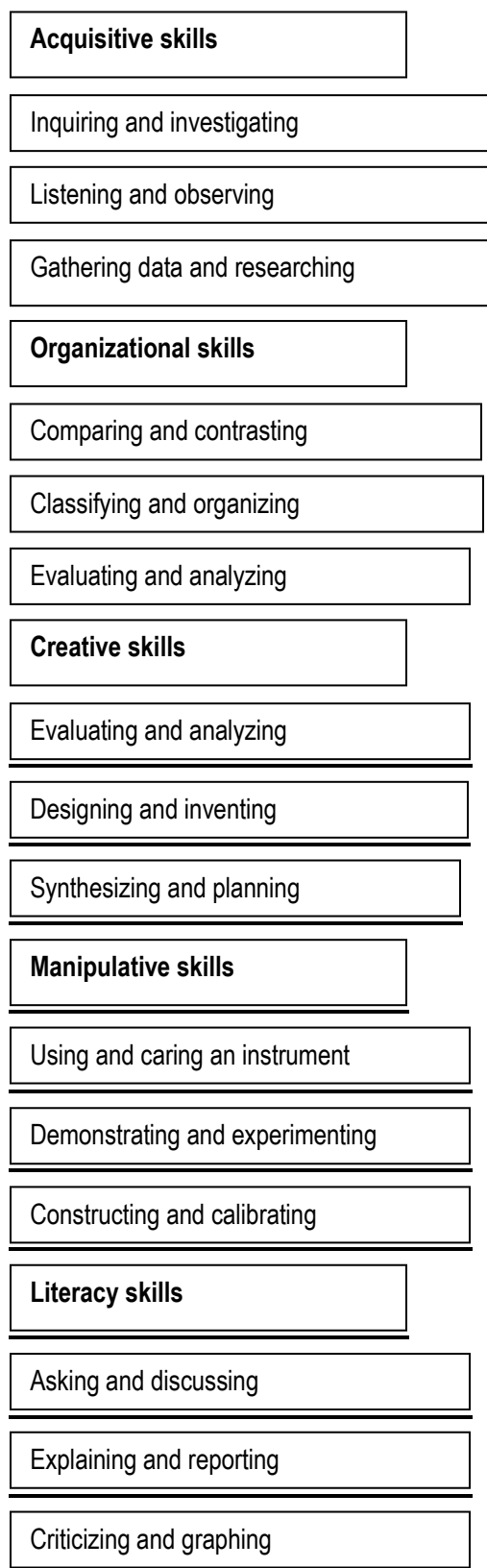


Figure 1. Strategies for developing scientific literacy (Bybee et al 2008).

A wide body of research suggests that raising questions, exploring and making observations as well as recording and analyzing a piece of scientific data are the central skills that will be desired by universities and employers in the future. (Chalufour 2010, Binkley at al 2012, Weng 2015). Some researchers called these skills '21st century skills' and grouped them as *tools for working* (Binkley at al 2012). The scientific process skills are needed to perceive surroundings and complex world to perform better in new situations that will challenge people in the computational world. Information and ICT literacy will be crucial abilities in analysis of research and making connections amongst different disciplines.

Scientific process skills play also a crucial role in STEM subjects (Science, technology, engineering and mathematics) that are one of the mostly emphasized concepts in the world (Devrim 2016). The STEM concept is characterized by interdisciplinary approach in which students learn by doing and connecting different peripherals of science. The International Technology and Engineering Educators Association (ITEEA) defines STEM as a *new transdisciplinary subject* that should be treated as a single course of study (Dugger 2010). Other researchers challenge the concept of STEM and suggest adding art subjects to make STEAM instead of STEM. Studies have shown that there are various connections between artistic abilities and engineering design (Sousa and Pilecki 2013). Furthermore, STEM subjects strongly focused on the development of scientific skills, creativity, problem solving and provide excellent opportunities for students to master innovation, technological literacy and life skills (Jones 2014).

The vast body of research shows that effective science teaching requires authentic learning (Herrington and Oliver 2000), opportunities to apply new learning through analysis (Heibert 1999) and problem-solving learning (Savery and Duffy 1996). All of the aforementioned approaches include development of scientific process skills and incorporating effective teaching strategies to enhance this process. Furthermore, research studies have shown that making a difference to students' learning is directly linked to effective teaching and instructional strategies used by teachers (Knobloch 2003). These findings have a number of important implications for the future practice. Teaching strategies shape the learning environment and engage students into learning (Hudson 2007). Therefore, it is crucial to use effective strategies that will lead to the students' success in terms of their academic achievements as well as building a set of skills needed in their future life.

The major objective of this study is to investigate which teaching strategies may impact on developing scientific process skills and are used by DP science teachers. In particular, this paper investigates the frequency of teaching strategies and determine whether the used teaching techniques can enhance development of scientific process skills. I will look more closely if there are any commonalities and difference between students' and teachers' perception of the usefulness of teaching strategies in developing scientific process skills.

This study aimed to address the following research question: Which teaching strategies can enhance the development of scientific process skills? This research will provide an exciting opportunity to advance our knowledge of developing process skills in DP science lessons. There has been little quantitative analysis of this area investigated before. The reader should bear in mind that that study is based on a relatively small number of responses of students and teachers. Hence, the results may be characteristic only for this particular cohort.

2. Materials and methods

I have decided that the best method to adopt for this investigation was to gather responses of DP students and science teachers through questionnaires. The group of students was represented by 20 pupils who constitute 10% of the secondary student population in an international school in Cambodia. They all study one of the DP science courses (Biology, Chemistry or Physics) and are aged between 17 and 19. The student group has included both males and females. A language diversity and nationalities of students who took part in the study have not been taken into account. The criteria for selecting the subjects were as follows:

- A student is aged between 17 and 19
- A student takes at least one DP science course (Biology, Chemistry or Physics)

The anonymous survey consisted of two questions: '*How frequently does your science teacher use the following teaching methods?*' And '*What is an impact of following teaching strategies on the development of scientific process skills?*' The possible answers for the first question have been designed using the Likert scale of frequency (1 – never, 2 – rarely, 3 – sometimes, 4 – very often, 5 – always). The answers for the second question described an impact level (1 - No impact at all, 2 - little impact, 3 - moderate impact, 4 - significant impact). In attempt to make each interviewee feel comfortable as possible, an online questionnaire has been sent via email.

The study also involved five DP science teachers who teach or taught DP science courses. They represent both genders and have different teaching experience as well as years of teaching science in the Diploma Programme. Teachers who participated in the study represent four different nationalities. They answered two questions: '*How often do you use the following teaching strategies?*' and '*What is an impact of following teaching strategies on the development of scientific process skills?*'

Both surveys included the ethical considerations as follows:

- Other parties will not have access to the raw data
- All names will be removed
- Participants will be provided with the purpose of the study
- Participants can withdraw at anytime

- The study is completely voluntary

The guidelines were adapted from the *Ethical guidelines for educational research* formulated by the British Educational Research Association and were included in both surveys.

Responses of both sample groups (students and DP science teachers) were collected and recorded for the further statistical analysis. The statistical analysis included calculating averages for the frequency of use of teaching strategies by DP science teachers, assessed by students and DP science teachers. Moreover, the averages have been calculated for the impact of teaching strategies on the development of scientific process skills. In order to measure the dispersion of responses from the mean, standard deviation (SD) has been calculated and presented in the tables with the processed results.

There are certain drawbacks associated with my quantitative analysis. The major limitation in this study was a relatively small number of samples, especially for DP science teachers. Further data collection will be required to determine exactly how teaching strategies enhance the development of scientific process skills.

3. Results

Table 1. The frequency of teaching strategies used by DP science teachers in DP science courses.

Teaching strategy	Frequency	SD
Animations	4.25	0.50
Analysis of secondary data	4.25	0.96
Lecturing	4.00	0.00
PowerPoint	4.00	0.82
Outdoor investigation	2.25	0.50

Table 2. The impact level of teaching strategies on the development of scientific process skills according to students and teachers.

Teaching strategy	Impact level according to students	SD	Teaching strategy	Impact level according to teachers	SD
PowerPoint	4.53	0.72	Indoor investigation	4.75	0.50
Demonstrations	4.18	0.88	Outdoor investigation	4.50	0.58
Indoor investigations	4.18	0.88	Analysis of secondary data	4.25	0.50
Self-directed reading	2.82	0.81	PowerPoint	2.50	0.57

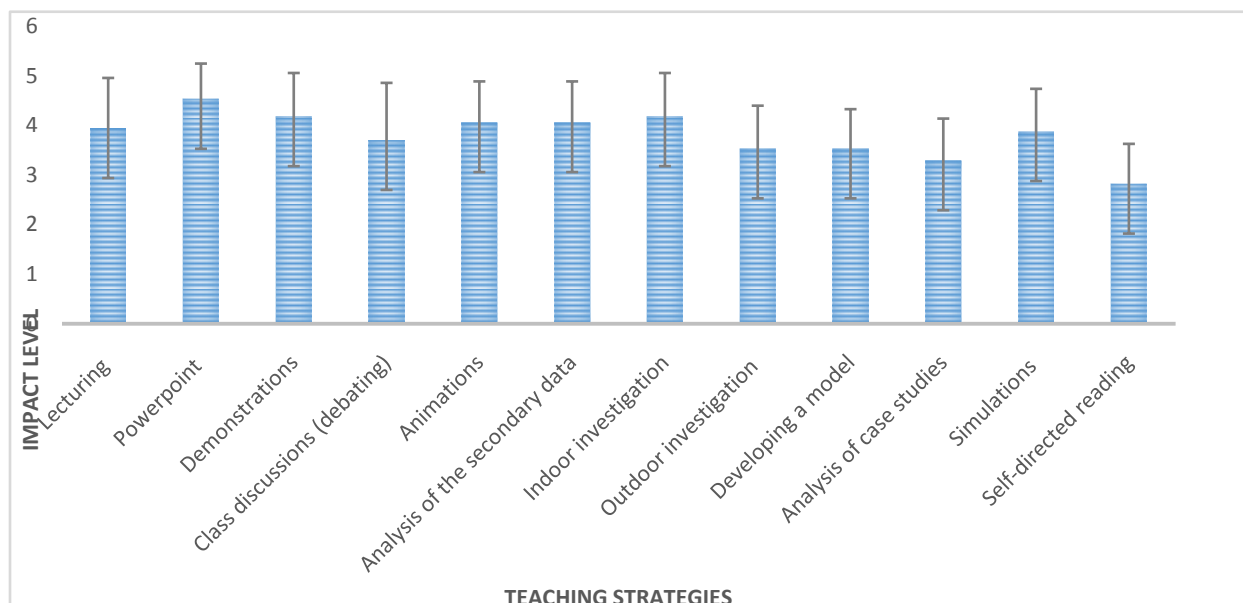


Figure 2. The impact level of teaching strategies on the development of scientific process skills according to students.

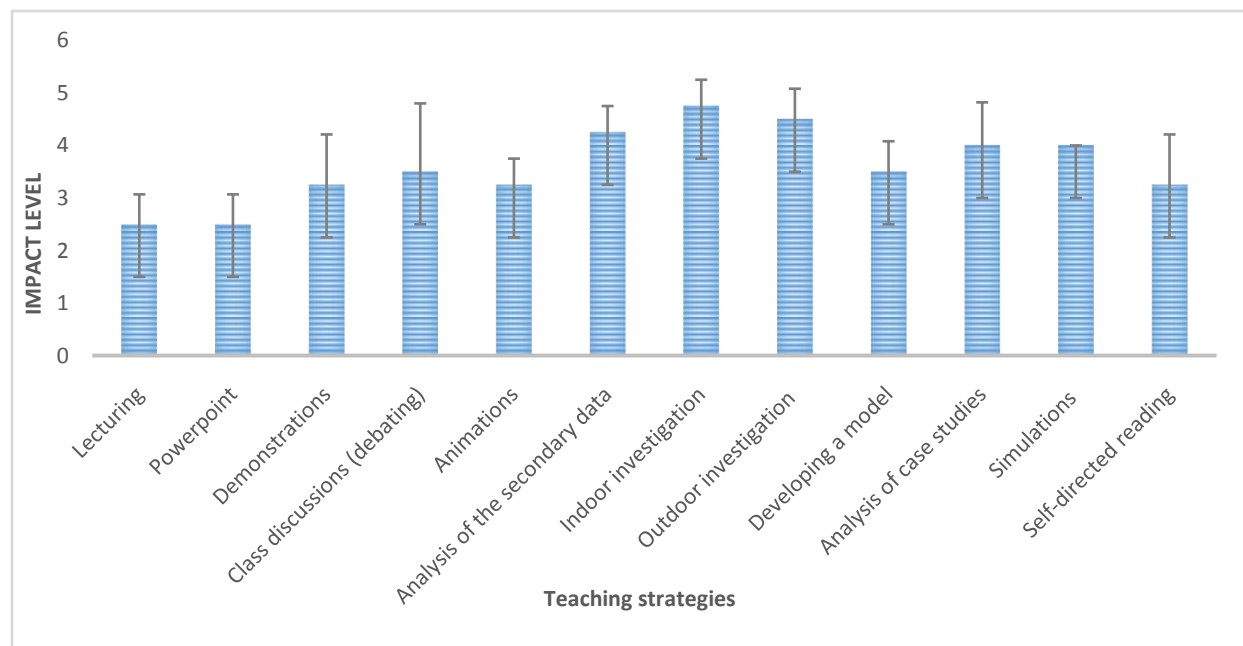


Figure 3. The impact of teaching strategies on the development of scientific process skills according to DP science teachers.

The results have shown that the most frequently used teaching strategies by DP science teachers were animations and analysis of secondary data followed by lecturing and using power point presentations (Table 1). The relatively low standard deviation for animations and lecturing suggests that these strategies are used by every DP science teacher. On the contrary, the standard deviation for the PowerPoint presentation and analysis of secondary data is significantly higher. It indicates that DP science teachers use these strategies with a different frequency. Interestingly, students have selected the PowerPoint presentation as the most commonly used strategy by DP science teachers. They also responded that demonstrations, indoor investigation, analysis of secondary data and animations were often occurring in DP science lessons. The standard deviation for these strategies shows a high dispersion of responses. Hence, the frequency of use of these methods varies considerably amongst teachers. The least frequently used strategy reported by DP science teachers was an outdoor investigation (Table 1). At the same time, students have concluded a self-directing reading as a rarely practiced method followed by the outdoor investigation. The standard deviation for both strategies was high and illustrates a great variation amongst students` responses.

In response to the second question a range of responses was elicited. The table 2 shows that the highest impact on the development of scientific process skills according to students has the PowerPoint presentation. Other strategies reported by students as high-impact strategies were demonstrations and indoor investigations. The lowest impact has been recorded for the self-reading (Table 2). The most striking result to emerge from the data is that teachers' responses were considerably different, especially for the impact of the PowerPoint presentation. According to DP science teachers this strategy has the lowest impact on the development of scientific process skills. The highest impact has been recorded for the indoor and outdoor investigation as well as for analysis of secondary data (Table 2). The standard deviation for these responses is relatively low and similar for all strategies. It suggests consistency in answers of all DP science teachers.

Interestingly, the results for students have shown a low differentiation of the impact level (Figure 2). The vast majority of teaching strategies were assessed as moderate (3) or significant (4) impact strategies. The exception was self-reading with the average impact level 2.82. Similarly, the differences amongst the strategies with the highest impact level (PowerPoint, demonstrations and indoor investigation) were statistically insignificant. Notwithstanding, the responses for DP science teachers were diverse and ranged from 2.5 (PowerPoint presentation and lecturing) to 4.75 (Indoor investigation) (Figure 3). It suggests that this sample group was able to differentiate effectively the impact level of the teaching strategies. Students seem to struggle to distinct the strategies and assess the impact level likewise the frequency of use of these strategies. This finding was unexpected and suggests that further research should be conducted to examine whether students understood the instructions. Another possible explanation for this might be that they were not able to differentiate strategies and their nature at the same level as DP science teachers. In conclusion, these results need to be interpreted with caution and cannot be extrapolated to the whole body of students.

4. Discussion

The successful teaching depends on several external and internal factors. The vast body of studies has investigated the effective methods of teaching science that can be summarized as follows:

- A content should be taught using the inquiry-based approach (Snow and Lauer 2005)
- A content has to be carefully selected and well structured (Garet et al 2001)
- Teaching should include hands-on activities (Loucks-Horsley et al 1998, Wenglisky and Silverstein 2006, Hudson 2007)
- Teachers should expand their set of teaching tools to facilitate student-centered course, including authentic laboratory experiences and demonstrations, simulation modelling (Hoskinson et al 2014)
- Teachers should provide opportunities to apply new learning through experimentation and analysis (Heibert 1999)

Hudson in his study concluded that 'high impact teaching' includes *teacher's enthusiasm, group involvement, usable and practical science, hands-on activities and interactivity with life*. He also emphasizes the importance of development of skills in science. His study identified low or negative – impact practices that involved: *teacher's lack of enthusiasm, chalk and talk or copying teacher's work and denigrating students' personal ideas*. This finding is similar with other studies and suggests that student-centered strategies have the positive impact on learning and engagement of students in science lessons. Taken together, current literature highlights the need for hands-on activities (Heibert 1999, Wenglisky and Silverstein 2006, Hudson 2007, Hoskinson et al 2014, Wieman 2014). When experiencing science through investigations, students are fully engaged and absorb knowledge more effectively. Wieman (2014) notes that active learning methods such as: indoor experiments, analysis of secondary data, demonstrations, problem solving tasks, achieve better educational outcomes. He argues that in active learning methods, students should spend a significant fraction of the class time on activities that require them to be actively processing and applying information in a variety of ways. Unfortunately, hands-on activities are often avoided, because they are complex and resource-consuming (Schreiber et al 2012). My results have shown that according to both groups (students and teachers), indoor investigations have a significant impact and may enhance the development of scientific process skills (Table 2). Hence, my study produced results which corroborate the findings of a great deal of the previous work in this field. An implication of these results is that DP science teachers need to be supported and provided a sufficient amount of preparatory time and resources to conduct hands-on activities. Hudson (2014) claims that *'usable scientific knowledge is always appreciated and valued by learners'*. This type of knowledge can be built through hands-on activities and is strongly correlated with scientific process skills. He also says *'the indoor and outdoor investigations connect real life to scientific knowledge and appeared to have a long-lasting effects on learners'*. These results provide further support that DP science teachers should be encouraged to make their classes as much practical and hands-on as possible. In future investigations, I can research whether these teaching strategies impact on academic performance of the DP students in science courses.

Both sample groups (students and DP science teachers) have concluded that demonstrations and analysis of secondary data can impact on the development of scientific process skills (Table 2). These strategies require less engagement of students and are easy to handle by teachers. Moreover, they can replace hands-on activities such as indoor and outdoor investigations and make the outcomes of an activity more predictable. Paul McCrory in his article 'In defence of the classroom science demonstration' says *'In addition to showing how important the under-valued skill of observation is in science, demonstrations can also allow you to exemplify scientific thinking and models of scientific method'*. He also highlights the students' engagement that can be build using demonstrations:

'Demonstrations can be emotionally engaging science theatre. Their unique power lies, like theatre, in their impact on the communal emotional engagement and focus of your students. Like theatre, demonstrations have enormous potential to – create and sustain interest;

stimulate curiosity; communicate and share emotions; reveal phenomena by showing, not just telling; direct focus; and to provoke further interaction, thought and discussion'. My findings observed in this study support appreciation of demonstrations by DP students and science teachers. These results have significant implications for developing a budget for the Science Department that should include materials needed to prepare demonstrations kits for students.

The analysis of secondary data is a strategy that allows students to access large sets of data and longitudinal studies. Teachers can easily extract and manipulate a piece of the secondary data to practice a certain skill, for instance interpretation of a graphical representation of results. This strategy develops observation and critical thinking skills. Hence, it may enhance the development of the scientific process skills. Additionally, in situations where resources are limited and teachers are not able to conduct experiments, analysis of secondary data offer a contact with practical aspects of science.

One unanticipated finding was that the PowerPoint presentation has been selected by students as the most effective teaching tool that may impact on the developing scientific process skills. In contrast, DP science teachers suggested that the PowerPoint as the least influential. The vast body of research suggests low effectiveness of PowerPoint presentations as a teaching tool (Bartsch and Cobern 2003, Ahmadi et al 2009, Yucel 2009, Urbanova and Ctrnactova 2009, Brock and Joglekar 2011, Prokop 2016 et al). PowerPoint presentations become a common component of every lesson. They replaced white boards and brought new technology to schools. However, this teaching tool has received much criticism regarding overuse and lack of contact with the audience (Hertz et al 2015). PowerPoint presentations offer flexibility in terms of choosing materials and allow to incorporate visual as well as auditory stimuli. In addition, they can be easily modified, stored and updated by teachers. Most importantly, PowerPoints are accessible online and can be shared and sent to students. On the other hand, their teaching effectiveness is low if the number and density of slides are too high (Brock and Joglekar 2011). Other studies suggested that slide images do not lead to increased interest of students in comparison with other visual stimuli (Bartsch and Cobern 2003). Some authors have speculated that slides are mainly designed on the basis of commonsense, instead of guidelines based on human information processing (Hertz et al 2015). In contrary to my results, studies have shown that students have a significantly less favorable overall view of PowerPoint presentations influence on learning than educators (James at el 2006). This indicates a need to understand the various perceptions of the use and impact of PowerPoint presentations that exist amongst students, teachers and researchers.

There has been little quantitative analysis of the impact on PowerPoints in science. The study on the use of realia (real samples) versus PowerPoint presentations on botany lessons suggests that activities with live plants increased participants' interest in plants than with the use of PowerPoints (Prokop at al 2016). In their analysis, participants' memory scores were highest in treatments with living samples of plants. On the contrary, some studies have shown that science lectures supplemented with presentations are more effective, interesting and helpful for learners (Urbanova and Ctrnactova 2009). Susskind (2005) points out that the results of students who were enthusiastic about PowerPoint presentations were not significantly better from the control group. In his research paper he explains the difference between the impression of the students and the proved effectiveness as a '*halo effect*'. He says '*the first impression does not reflect the long-term experience*'. In general, it seems that there is abundant room for further progress in determining the effectiveness and impact of PowerPoint presentations on the learning and developing the scientific process skills. Undoubtedly, this is an important issue for my future research.

In the light of recent studies, PowerPoint presentations do not enhance learning and may have a marginal effect on developing scientific process skills. Since students do not interact with living samples and scientific apparatus, they have limited opportunities to practise their manipulative skills. Furthermore, they do not develop their observation and critical thinking skills, due to the static nature of presentations. Contrary to expectations, students' responses indicated a high impact of PowerPoints on the development scientific process skills. The possible explanation for it is a hypothesis that students perceives this tool as the most appealing and attractive visually. They might greatly appreciate a variety of stimuli that can be offered by a PowerPoint presentation. It offers auditory, visual and virtual elements that are very common in their life nowadays. This finding may also suggest that students are already addicted to online resources and expect to be exposed to them in science classes. However, with a relatively small size of sample group, caution must be applied, as the findings might not be transferable to other learners. Definitely, this unexpected result has thrown up many questions in need of further investigation and has a number of important implications for future practice.

Returning to the research question posed at the beginning of this study, it is now possible state as follows:

- Indoor and outdoor investigations have reported the highest impact level. Thus, they may significantly enhance the development of the scientific process skills;
- Demonstrations and analysis of secondary data have a moderate impact and may enhance the development of a limited number of scientific skills, such as observation and critical thinking skills;
- PowerPoint presentations have a little or no impact on the development of scientific process skills, but are considered by students as an attractive and stimulating teaching tool;
- There is significant difference between DP students' and science teachers' perception of the impact of PowerPoint presentations on the development of scientific process skills that should be further investigated.

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