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Implementing the Introduction, Methods, Results and Discussion Article Structure in Engineering Education based on Problem-Based Learning

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ABSTRACT

The organization of knowledge influences how effectively students learn, so that if the information is well structured and the knowledge acquisition process is carried out in a systemic way, one can more effectively retrieve pieces of knowledge. To tackle this problem a common document format used in academia, IMRaD (Introduction, Method, Results, and Discussion), can help students in natural science and engineering education to approach the problem of knowledge organization in a systemic way from the beginning of the learning process.

In this study, we explore the use of the IMRaD format for students pursuing undergraduate and master's degrees as a tool for learning whilst making the project report more comprehensible for readers. The predefined document structure cannot be considered the solution to all learning issues and it should not limit the unpredictability, which is necessary during the creative thinking typical of the research environment.

Keywords: IMRaD report format; knowledge management; project learning; problem based learning; problem solving

INTRODUCTION

Universities around the world have started adopting research-based methods for education from undergraduate curricula with the motivation to increase critical and innovative thinking among students and promote research findings outside the university walls (Oriokot, Buwembo, Munabi, & Kijjambu, 2011). Students therefore face

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challenges when approaching the research methods that at the first instance may seem unstructured and characterized by many tacit rules.

Project- and Problem-Based Learning (PBL) have also become distinctive methods in students' education (Mills & Treagust, 2003). This approach is motivated by the need to train students in a working method, which is close to the real world (Graaff & Kolmos, 2003). In this context, the project is selected, scoped and framed to serve as the ecosystem for learning the course contents through practice and implementation of the theory. However, it has been demonstrated through numerous cases that there is a need to increase student support and coaching in acquiring a reporting style that conforms to academic standards. This is supported, for instance, by Oriokot et al. (2011) where it was found that student teams with less support from faculty members were less likely to follow the IMRaD format while drafting their reports. This led to the conclusion that actively supporting undergraduate research could yield beneficial results in acquiring fundamental academic writing skills.

Academic articles written in a recognizable format such as IMRaD, can also help readers who will be able to readily find information in the report. Wu (2011) mentions several studies in which readers deem papers with a well-organized abstract to be superior to the ones that do not show a clear structure.

Wittek, Askeland and Aamotsbakken (2015) analysed how students approach the writing process and revealed that novices tend to approach writing as mere "reporting": they write to present data and facts. Writing plays an important role in students' learning because it puts them in an active position to clarify the world as it appears to them. In Wolfe, Britt, and Alexander (2011), authors report a decline in the teaching of good technical writing in education, and as a consequence teachers have increasingly relied on "reactive teaching methods". This means that writing instruction occurs only when the student's problem arise and the instructor deems it appropriate to comment. The authors show evidence that students who were explicitly taught technics for scientific writing performed better then who were not taught any specific strategy. Kirschner, Sweller and Clark (2006 pointed out that, in an education context, approaches with minimal guiding instructions are found less effective and efficient than educative approaches with an emphasis on extensive guidance, because of incompatibility between the human cognitive architecture and the teaching methods of minimal guiding instructions. The importance of the writing process in emphasized in Petersen (2018), where it is suggested that thoughts are organized verbally in our mind, and therefore learning to think through writing helps develop an organized and efficient mind.

Writing requires that the student organizes knowledge as a hierarchy. Reif (1987) emphasizes that organizing knowledge is a complex exercise; generally, it is more difficult to create such a structure than use it. To explain the point, the analogy of a geographical map was used. Most people can use a map, but to create a map is a much more complex task which requires systematic organization of information.

In all, PBL is becoming a growing trend in education and is posing a need to develop new strategies for teaching students. In this context, the aim of this paper is to analyze why the systematic and well-structured framework provided by the IMRaD format can facilitate student learning by explicitly indicating the contents in each section of the report. The analysis is to be considered in the context of a problem-based education where students are requested to solve a problem during the project time. Additionally, we assume that the IMRaD format is implemented in the context of engineering education, where the problem formulation both reflects the nature of the engineering project and enables students to expand on one another's work.

In this paper, we first discuss the challenges that students face when organizing a large amount of knowledge in a project report. This effort is associated with the definition and the solution of a project's main questions; then, we analyze the phases and challenges during the problem-solving process. After that, we describe the main phases of the project and the main sections of the IMRaD report format. Finally, we discuss how teaching the IMRaD report format can contribute to student learning.

MATERIAL AND METHODS

The scientific literature on the relevant topics constitutes the knowledge base for this study. In order to understand the impact of the IMRaD format on the student learning process, three main subjects were investigated: (1) the organization of knowledge in the learning process, (2) the major phases involved in the problem solving, and (3) the project life cycle phases.

As criteria to select the relevant literature in the different subjects, we aim to find well-established models in project management and problem solving in the field of cognitive science and education. We analyze how the learning process occurs when students have to organize the knowledge to solve the project problem over a framed period, with the intent to show how the IMRaD format can promote the student objectives.

In particular, we start documenting the implications of organizing knowledge during the learning process. We then describe the main phases of problem solving identified in the literature. In doing so, we gain a better understanding of the cognitive process in learning.

Since the problem solving occurs throughout the project period, we investigate what the main project phases are and their correlation with the problem-solving phases. For instance, it will become evident that the problem definition will be performed in the early stage of the project, while the problem conclusion will be towards the end of the project.

The identified problem-solving phases and project phases are useful to debate later in the Discussion section, which outlines how the IMRaD format can promote student learning and knowledge organization and how this paper structure resembles both the identified main project and problem phases.

RESULTS

The results section is organized in four parts, where the first three parts are meant to justify the importance of the IMRaD format in the context of education. Thus, the four parts are the organization of knowledge, the problem-solving and project phases, and finally the IMRaD format description.

Organizing knowledge in educational context

Interpreting and organizing scientific concepts is a complex exercise, which differs from common everyday tasks (Reif 1987). Knowledge can be organized in different ways; however, a systematic organization can increase the performance of students. Reif (1987) found that inexperienced students tend to remember bits of knowledge without a coherent knowledge structure. This can be attributed to the tendency to memorize facts and formulas. In many cases, they are unaware of ways to effectively organize knowledge during their learning process. On the other hand, experts have coherently organized knowledge such that it is easy for them to infer detailed information. If well organized, information can be easily retrieved; this is particularly true in the case of large amounts of knowledge. Moreover, in science there is a need to make good connections among different pieces of information.

In hierarchical knowledge organization, the most important piece of knowledge is intended to be the one that helps the most in the attainment of the overall goal. Subordinate knowledge is less important and is useful for solving specific goals. In Eylon and Reif (1984), evidence was shown that knowledge, when organized according to clear principles and tasks, is easier to apply and consequently increases student performance.

In science, we use unifying principles, which provide a general understanding of a physical phenomenon. These principles provide the building blocks to solve problems. Inexperienced learners can have a fragmented and poorly organized knowledge, which leads to poor application of the concepts that can be easily forgotten after a short period. Even instructors can come with some poor organization of lectures, if there is little effort to arrange the knowledge globally across the course lectures. In this way, the task of organizing knowledge is left to the responsibility of students, with the consequence that students' knowledge remains poor.

Problem solving phases

Problem solving is a process, which is motivated by the necessity to accomplish a goal. Its difficulty depends on the complexity of the problem in itself and the ability of the solver. A problem can be solved using different strategies; however, some major phases can be highlighted. Different authors have investigated the cognitive process involved in the problem-solving process. Among others, Reif (1995, 2010) defines basic problem solving in the four following phases:

"(i) describing the problem; (ii) analysing the problem; (iii) constructing the solution; (iv) assessing the solution."

In the initial phase, a description of the problem with all the needed information is created. The second phase involves the problem analysis in which relevant theoretical concepts and principles are recalled to develop a more analytic description of the problem. Consequently, a solution is constructed. A problem may be divided in multiple sub problems, and lacking information must be covered by the solver existing knowledge. If this initial phase is not correctly done, the subsequent work can produce wrong results. In the third and last phase, the solution is checked. It is essential to evaluate if the solution is correct and in order to do so some standard checks must be carried out (i.e. consistency of units of measurement, validation of results against previous results). An additional phase can involve exploiting the solution to solve other similar problems.

A similar definition was provided by Carlson and Bloom (2005), where the authors define what they call a "Multidimensional Problem-Solving Framework". In this case the problem-solving process was studied for the discipline of mathematics, and it is constituted of four phases:

"(i) orientation, (ii) planning, (iii) executing, and (iv) checking"

During the orientation phase, the problem solvers puts their effort into making sense of the provided problem information and constructing a logical representation of the problem. In this phase, goals are defined. In the planning phase, the focus is on accessing previous knowledge, algorithms, and schemata that can help solve the problem and construct a solution approach. During the execution phase, the solution approach is implemented. During the checking phase, the proposed solution is verified for reasonableness and correctness. A decision is made regarding the validity of the solution.

These four problem-solving phases closely resemble the ones previously defined by Reif (1995). Both the presented frameworks are characterized by being cyclical, meaning that during phase four, if the solution is not satisfactory, a new cycle starting from phase two is engaged; the problem is re-analyzed and a new solution approach is constructed. This cycle occurs multiple times when attempting to solve a problem and therefore the process is far from being considered linear. In this regard, Olsen and Pedersen (2005), chapter 2, says that the problem formulation requires most of the work at the beginning of the project, but it can be reformulated several times during the project and is closely connected to the conclusions. When the students' group finds a solution for a sub-problem, the original problem formulation can be re-assessed and further clarified. At the end of the project, both the problem's formulation and conclusion are reassessed to make the project coherent.

Reif (2010) emphasizes that, in the science domain, problem solving requires a substantial amount of well-connected conceptual knowledge and a systematic approach so that mere cleverness will not be sufficient to construct a correct problem solution. Good problem solvers tends to spend more time in the first phases, namely describing and analyzing the problem, while inexperienced students tend to focus on the construction of the solution, and sometimes they are not aware of all the knowledge required to solve a problem. Similarly, good students tend to reason around a few important principles and concepts rather than use knowledge from a previous similar problem. Based on these considerations, instructors should focus on explicitly teaching the decision process needed to solve a specific case, with all the potential options, and making sensible choices rather than describing one example. In this regard, Sweller and Cooper (1985) found that abstraction of general rules requires an exposure to different schemata for constructing a solution.

Emotions and good attitude can also play an important role during the problem solving. With regard to this, Carlson and Bloom (2005) found that making correct decisions during problem solving depends not only on the ability to draw from well-connected conceptual knowledge, facts, and schemes, but also on the ability to manage emotional response during the process. Experienced problem solvers tend to be more self-aware and therefore control their emotional response better. The less experienced may not notice when their effort is following an unproductive direction, and therefore this can lead to frustration.

Problem-based learning is a good environment to develop a new mental model that values connecting theory and practice, develops collaboration, and acquires a better control of the learning practice (Askell-Williams, Murray-Harvey, and Lawson 2007). On the same line, Hmelo-Silver (2004) found that, through the experience of solving a problem collaboratively, students construct a knowledge base, become more independent and motivated to find the learning direction, and learn to effectively collaborate with their peers and other stakeholders. By becoming an autonomous learner, the student will be able to apply these important lifelong learning skills and metacognitive strategies in his future professional life.

Project life cycle phases

In a project-based learning context, the problem solving occurs over an extended period of time, generally a few months, which coincides with the beginning and the end of the project. A project task simulates an experience that is close enough to the professional world where the team and different stakeholders are involved at a different time. According to HBR (2016), in the life cycle of every project, we can identify the four phases listed below.

Planning. The real problem that needs to be solved is identified and defined. The project stakeholders are identified and the success criteria are defined. The project objectives are planned.

Build-up. After the planning phase, the estimates previously conducted become commitments in terms of resources. In this phase, precise resources for solving the project are put together.

Implementation. During the implementation phase, the plan is put into action. In this phase, it is important to control the time and report progress to the stakeholders in frequent meetings.

Closeout. During the final phase, the focus is on delivering the results to the relevant stakeholder and assessing the quality of the output.

These phases are so broadly specified that similar stages are found during a project in the educational context.

IMRaD report format description

Several comprehensive guidelines were developed for helping students to write a report according to the IMRaD format (Cuschieri, Grech, & Savona-Ventura, 2018; Gastel & Gastel, 2013; Manterola, Pineda, Vial, & Grande, 2007; Mateu Arrom, Huguet, Errando, Breda, & Palou, 2018). The guidelines in Morley (2018) provide the phrasal elements commonly used in each section of the IMRaD report. The author suggests that there are recurrent phraseological patterns that are used in academic language that are worth acquiring, especially for non-native English speakers. The benefits of teaching students recurrent language patterns were analyzed by Wolfe et al. (2011). Moreover, course material and handouts for academic writing including the IMRaD format have been produced by many universities.

In Meadows (1985), the reasons for the popularity of the IMRaD format in the scientific community are outlined. In the study, it is suggested that this construction is the consequence of an evolutionary process aimed at simplifying the complexity of a scientific report so that authors can address the typical common questions of a scientific study. There are also advantages for the editor and reviewers, who will find it easier and more time-efficient to evaluate the manuscript and find specific pieces of information in the structure blocks without reading the entire document. Considering the large number of rules in scientific writing, Luby and Southern (2011) wished that editors could permit more lenient requirements in academic writing standards from young researchers.

Szklo (2006) examined how different reader types approach science articles written in the IMRaD format. The results of a survey showed that the reading strategy depends on the specific reader role: scientist, editor, and reviewer. For instance, scientists tend to read strategically; they jump to the section that can provide the needed information. Second-language readers require more cognitive effort during reading; therefore, they may be more interested only in the sections rich in information, such as the results and discussion. On the other hand, reviewers and editors look at the paper as a "raw product". Reviewers for instance start focusing on the soundness of the methodology description. Editors scan the paper from beginning to end to make sure that it adheres to academic standards.

Below we list and briefly describe the main content of each IMRaD report section. As often suggested, each section responds to a precise question (Manterola et al. 2007; Mateu Arrom et al. 2018; Wu 2011). The names of the sections in some articles can be slightly different. In some cases, these sections can be merged into one for convenience (e.g. "Results and discussion"). Even with these slight variations, the structure remains the same.

Introduction. (Why the study was done?) The introduction serves to put the work into context. It starts with the background of the study from higher level down to the specific problem addressed in the study. The section should contain the general context that motivated the study, a review of the relevant literature on the subject, a clear definition of addressed problems with hypothesis and research questions. The final paragraph is generally used to outline the structure of the report.

Methods. (How was the study done?) In this section, we describe in details the research procedure. We generally start with the problem theoretical assumptions, after we present the procedures and techniques used to solve the case. In quantitative research, data is collected through modelling or experimental testing. If the study involves modelling, the physical equation should be accurately reported. If an experimental study is done, the test procedures and the data analysis should be described in details. The information provided should allow other researchers to reproduce the study.

Results. (What did the study find?) The main findings are reported and commented in a systematic and detailed way. In an engineering study, we usually report quantitative results in plots and tables. Each of listed results should be described with the interpretation of the physical phenomena. In the results' presentation, it is important to link and comment them to the methods previously described and relate them to respond the research questions.

Discussion. (What is the relevance of the study?) This section is a further elaboration of the results previously described. Differently from the results section, here we present the results connecting them with each other and with the results in open literature. The section begins with a brief summary of the results explaining how they link to the initial objectives. We then describe the main conclusion that can be draw from the results. We explain how the conclusions fit in the global scientific understanding. Finally, we propose how the conclusions can be practically implemented and what are the major limitations.

Conclusion. (What are the major findings?) This section summarize the purpose and motivation of the study. The results are then briefly reformulated with the most general arguments and future work is outlined. The results should be clearly connected to the research questions outlined in the introduction. This section should be written so that a reader should be able to understand the key messages in the paper without going through the details in the results and discussion sections.

Reference. This section provides the list of articles, books and webpages cited in the text. Mack (2016) emphasizes that, in scientific papers, citations serve to provide sufficient context and background to the reader, to establish credibility, to validate and compare the presented 'facts and figure' and finally to acknowledge other people ideas. In general, citations should be carefully chosen to help the reader navigate in the large amount of information provided in a paper.

To conclude, it is obvious that in the writing process, we will not write the IMRaD sections sequentially, however this format will help us to organize portions of knowledge with the additional advantage that the readers will be able to find the information. The phases of the writing process were reported in Olsen & Pedersen (2005), Chap. 4. The author identified four overlapping phases i.e. "ideas, contents, form, text retirement and evaluation".

When comparing the IMRaD format with other report formats for students in PBL education, the project report sections list defined in Olsen and Pedersen (2005), Chap. 14, may come useful. The author suggest the following sections list: "(1) The preliminaries; (2) Introduction; (3) Analysis; (4) Conclusion; (5) Final touches". The structure presented here is very similar to the IMRaD structure. In fact, the third block, "Analysis", includes the method, results and discussion sections of the IMRaD format. The main difference between the two formats is that the IMRaD format has a clear distinction between the information that should be included in the method, results and discussion sections, while the other format leaves more freedom to students in the way they want to arrange the information in the main body of text.

DISCUSSION

IMRaD structure contribution to student learning

In the previous sections, we have seen how learners organize knowledge in an educational context based on project- and problem- learning. In engineering, a project report addresses different goals connecting the needs to acquire and organize a large amount of knowledge and describe the problem solving during the project period. Figure 1 attempts to depict the process of writing a report in the IMRaD format in the context of project and problem based learning. The report sections shown in the bottom layer and the project phases shown in the top layer are related to the problem phases shown in the middle layer.

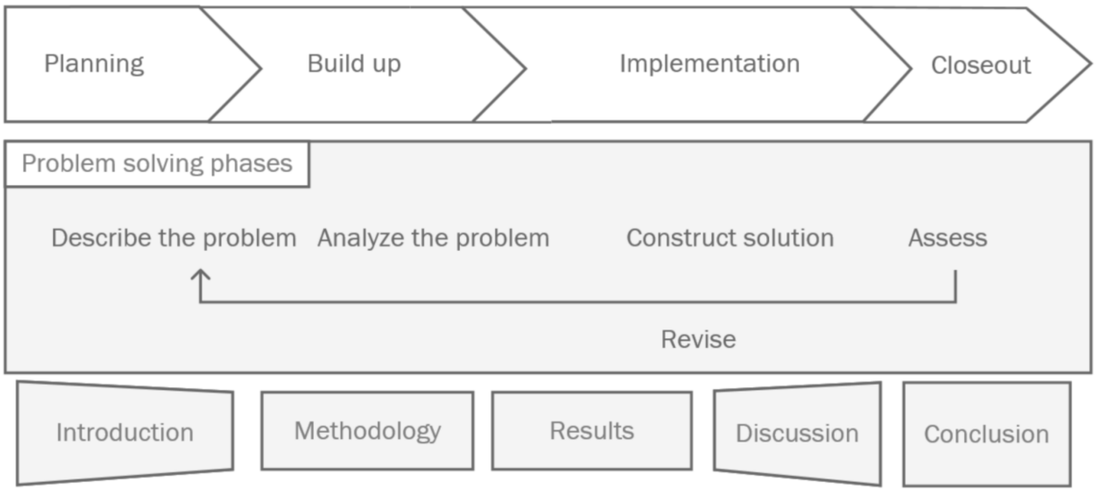

Figure 1. IMRaD format in the context of project- and problem-based learning; Project phases (HBR, 2016); Problem solving phases (Reif, 1995, 2010).

In the top of the figure, we can see the previously described project phases. These phases have different durations, with the implementation phase taking generally a longer time. In the first part of the project, namely "planning" and "building up", the student is focusing on describing and analysing the problem. At this regard Dahl (2018) points out that in the educational context the problem formulation is not originated by observations but rather by a practical or empirical problem which is edited by the teacher to fit the learning goals.

The initial project phases will be reported in the introduction and methodology chapter of the report. The students' team investigate the state of the art of the technology, review the scientific literature and discuss with supervisor and other project stakeholders what are the initial information and the best methods to address the problem. In these phases, they should also formulate some compelling and detailed research questions and a list of assumptions.

During the implementation, the results are produced and discussed. The students will be in this case involved in constructing a solution and assessing it. This phase is usually labour intensive as it can require, for instance, to set-up an experimental campaign or to develop a software model simulation and perform some data analysis. Some inexperienced students may dive straight in the implementation phase without carefully planning and analysing the problem solution with the intent to accelerate the process. In this case, the risk is that they may later find themselves following an unproductive direction.

In the project closeout, the students will be involved in the testing and validation the solution and describing the concluding remarks in the final section of the report. The report is entirely revised and the research questions are readjusted to fit the results that were actually achieved. Additional simplifying assumptions, which were necessary during the problem solving, can be added at this stage.

We have previously emphasized that both the problem solving and the writing process are cyclical rather than linear. This means that the sections in the report are not written sequentially but they are refined over the time once the problem analysis becomes clearer, similarly paragraphs that becomes irrelevant are omitted, arguments that are not convincing enough can be improved. The writing process is helpful also for the students to discuss and validate their knowledge with their peers and supervisors once is put down on paper.

During the project, students have to work at different levels. This can include, for example, learning a new software, mastering new concepts and developing the ability of teamwork. Acquiring good reporting skills in a specific academic format is an additional level of complexity that students will have to deal with. Due to the overlapping of different learning objectives, new students may experience "cognitive loading". This will reflects in the quality of the report. Beginner students will focus more, for instance, on descripting of the methodology and results rather than connecting and discussing the different results and making sound conclusions. This can be explained with the fact that problem-solving process requires already a large effort so that there is no room for more general abstractions. Sweller (1988) argued that developing a good curricula structure and providing good explicit instruction can reduce the cognitive load especially in the early stages of learning.

CONCLUSION

Effective communication of academic results is an integral part of education. Teaching the value of having strong knowledge organization can be very helpful to students. In this paper, we discussed how the learning process occurs and how students organize knowledge. In published works, we found that knowledge organization is fundamental in science, as areas of knowledge are closely connected and arranged by importance. Moreover, we have seen that problem solving occurs during four major phases. This process is cyclical rather than linear, meaning that if the problem's solution is considered unsatisfactory, a new analysis of the problem must be performed.

Writing a report in the IMRaD format can help students reorganize their knowledge in a systematic way. This is relevant especially for students pursuing undergraduate and master's degrees, which are not necessarily exposed to a research environment. It will be useful in their future careers when they will need, as members of the scientific community, to read (and in some cases write) scientific papers.

By comparing another format for students in PBL education, we have seen that the IMRaD format has a clearer format in terms of how information should be included in the method, results, and discussion sections, while the other format may allow more freedom for students to choose how to distribute the information. This suggests that the IMRaD format provides a more constrained framework and clearer organization, which may be helpful to students who are learning the craft of writing. Furthermore, from a literature point of view, it appears that providing explicit guidelines on how the contents of each report section should be presented can be advantageous for students.

The sequence of information in the report roughly resembles the problem-solving process. We emphasized that the predefined IMRaD sections should not limit the variable creative elements that are typical of the research process.

This study raised many questions that will need further empirical analysis. It would be particularly interesting to complete a survey of students to understand what impact learning to write using the IMRaD format has on them. The ultimate goal would be to find out what the best strategies are for teachers to use to promote both effective learning and good academic standards in the context of problem- and project-based learning. Moreover, the findings could be used to develop an IMRaD report template with guidelines that better fit the needs of students.

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