Research in Engineering Education Symposium &
Australasian Association for Engineering Education Conference
5 – 8 December, 2021 - Perth, WA

Promoting Students' Conceptual Change in Statics through Self-Explanation Strategy in a Remote Learning Context

Jose L. De La Hoz[1], Camilo Vieira[1], Alfredo J. Ojeda[1], Gabriel Garcia-Yepes[1]
Universidad del Norte[1]
Corresponding Author's Email: vegalj@uninorte.edu.co

ABSTRACT

CONTEXT

Statics is a fundamental course in engineering, representing one of the main challenges for students to complete their engineering programs. Statics is also a prerequisite to different subsequent subjects where problem-solving and spatial visualization skills are essential. The traditional teaching of Statics is insufficient for students to achieve successful learning of Statics.

PURPOSE OR GOAL

This study explores how different conditions of worked-examples integrated into a spatial visualization tool named "*Hapstatics*" promote conceptual change in Statics. Students engaged in active exploration of these examples by self-explaining them. These activities took place in the context of remote education due to the COVID-19 pandemic.

APPROACH OR METHODOLOGY/METHODS

This study included 54 undergraduate engineering students enrolled in a Statics course distributed into three groups. Each group wrote self-explanations for each step in a correct, incomplete, or incorrect worked-example in the context of Statics equilibrium. The *"Hapstatics"* tool was used to support conceptual understanding of static equilibrium. Students completed a pretest and a posttest, and the researcher team used inferential statistics to identify possible changes in students' conceptual knowledge.

ACTUAL OR ANTICIPATED OUTCOMES

The results showed a considerable improvement on student conceptual understanding in the posttest for the incomplete worked-example condition. The complete and incorrect worked-example conditions did not show a statistically significant result.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

This study suggests that engaging students with a Statics interactive worked-example using a self-explanation strategy may promote conceptual change. We recommend working in strengthening their spatial visualization skills in learning Statics throught the use of spatial visualization tools.

KEYWORDS

Metacognition, Problem-Solving Skills, Statics, Worked-Examples, Self-Explanations

Introduction

Previous research about engineering students has shown that a good academic performance does not mean that students acquire a proper understanding of fundamental engineering concepts (Foutz, 2018; Montfort et al., 2009; Haron & Shaharoun, 2010). Statics is considered an essential subject for different disciplines, which require critical analytical problem-solving skills, a necessary objective for engineering education. Thus, the course of Statics becomes a supporting pillar for engineering design and applied engineering. Hence, the use of specific teaching strategies for Statics requires great effort and attention (Steif, 2004).

For many students, Statics is an important but challenging engineering course. These beliefs tend to negatively impact their performance in this subject and, therefore, in subsequent ones. Students' study habits, often poor and unmotivated by the prejudices formed around the subject, plus the complex Statics concepts, are constant obstacles for the students' learning process. A correct understanding of Statics enables students to relate the forces with the interactions between the elements, but students often have difficulties perceiving the forces between inanimate objects like Free-Body diagrams (Steif & Dollár, 2005). They also have problems understanding the reactions and forces between the components of structures and machines (Goodridge et al., 2014; Litzinger et al., 2010).

Strengthening students' problem-solving skills will be crucial for comprehending the topics studied in a Statics course. When students try to solve Statics problems, conceptual gaps are reflected in their solutions, resulting from the traditional pedagogical strategies. These are important reasons to reflect on the pedagogical strategies used in Statics and students' prior knowledge.

In this study, we used a spatial visualization tool called "*Hapstatics*" (Walsh et al., 2018), integrated with a self-explanation strategy in the context of remote education. *Hapstatics* allows students to identify the forces and reactions acting on a structure under specific conditions. This simulation was integrated along with self-explanation activities to elicit student metacognitive skills. Metacognitive skills enable students to be more aware of their own learning process (Chi, 2000). This study aims to explore whether this integration support student conceptual change. The guiding research question for this study is:

RQ1: ¿Which of the strategies are most effective for improving students' conceptual knowledge after self-explaining an either correct, incorrect, or incomplete worked-example?

Conceptual Change

Conceptual change is the theoretical framework guiding this study. Conceptual change refers to the process where conceptions are changed or replaced by new conceptions, promoting a restructuring of knowledge (Posner et al., 1982; Strike & Posner, 1992). To promote conceptual change, the teaching strategies must support students to locate and/or externalize their conceptual errors. This process also helps to understand the newly acquired conceptions better and strengthen these through practice (Anderson & Smith 1987, as cited in Vieira et al., 2018). The action to address their own misconceptions is known as "accommodation" (Posner et al.,1982). To optimize the teaching practices in Statics, these should consider students prior knowledge and conceptual gaps, which are a determining factor for students to use adequate conceptual knowledge in problem-solving. The conceptual conflicts existing in students' mental model may enable the conditions to externalizing students' prior knowledge and enabling cognitive accommodation (Schraw et al., 2006).

Metacognition and Self-explanations

Metacognition is a higher-order mental process where students can develop the ability to reflect on their learning products and cognitive processes (Flavell, 1976; Moore & Carling, 1982; Gavelek & Raphael, 1985). Planning, monitoring, and evaluation are three metacognitive strategies involved in cognitive regulation (Brown et al., 1983: Flavell & Markman, 1983). These strategies enable students to learn on their own, acquire better-structured knowledge, increase their motivation for learning, and a greater success in tasks to solve.

Self-explaining is a knowledge-building activity directed by students who generate explanations for themselves, going beyond the information provided, starting, generally, from a written text that makes a procedure explicit, and usually within a learning context (Chi, 2000). Self-explaining helps students identify gaps in their understanding and missing information in the delivered text or studied example, and supports the construction and repair of their mental model. Self-explaining demands to be more aware of their learning process by monitoring their understanding of the material. Thus, self-explaining may help to externalize student comprehension and elicit the development of metacognitive thinking (McNamara & Magliano, 2009. These are critical conditions for conceptual change.

Spatial Visualization

In Statics, students must develop skills for spatial visualization to be able to extrapolate Physics and Statics concepts into problem-solving. Spatial visualization refers to the ability to manipulate an object or geometric figures mentally (e.g., to turn, to twist; Alias et al., 2002). Teachers in different areas of engineering tend to represent 2D and 3D movements using diagrams and inanimate objects. This approach increases the difficulty for students when trying to interpret forces and reactions between elements in contact. Including spatial modeling within the teaching and learning of Statics would reduce students' cognitive load and converge in better results on students' understanding of Statics.

Methods

This study employed a multiple case-study crossover design (Yin,2009) to analyze and compare each case against another. Each case study corresponds to a worked-example type, one for each group of students. The goal is to identify which strategies are most effective for improving students' conceptual understanding in Statics among a correct, an incorrect and an incomplete worked-example. The cross-case study design enables the research team to identify differences and similarities within and between each of the three cases (Khan & VanWynsberghe, 2008).

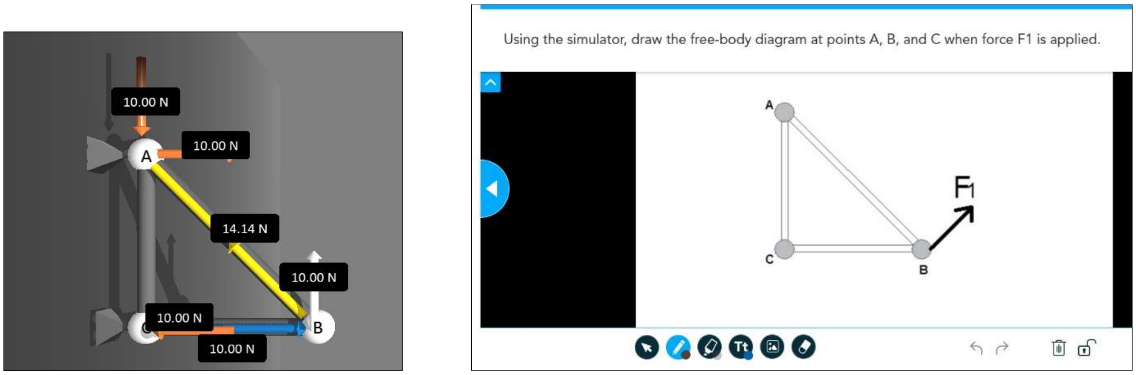
Participants and Procedure

This study included three groups of a Statics course at a private mid-size Latin-American university. A total of 91 students enrolled in this course during the fall semester of 2020 participated in this study. Participants were divided into three cases according to the type of worked-example they self-explained: correct, incomplete or incorrect worked-example. The study started from a pilot phase in the fall semester 2019 (De La Hoz et al., 2020) with the participation of three students in a think-aloud protocol. Later, a subsequent study was implemented during the spring semester of 2020 with 147 students divided in two cases: an incomplete and an incorrect worked-example. The pilot phase offered us a preliminary coding scheme that served as a starting point for the rest of the study. The second phase allowed us to refine our coding scheme and identify the effectiveness of these approaches in a classroom environment.

The procedures for this study include: i) Students first completed a pretest, assessing their conceptual understanding of Statics equilibrium; ii) The incomplete and incorrect worked-example groups completed a spatial visualization activity using the *Hapstatics* simulator (Figure 1); iii) Students wrote their self-explanations for the correct, incomplete or incorrect worked-example of static equilibrium, divided into five steps (Road map, modeling, governing equations, computation, discussion, and verification; Gray et al., 2005). Since students accessed the session remotely, we use the platform *Nearpod* to collect their self-explanations. Figure 2 depicts a section of the complete, incorrect, and incomplete worked-examples; iv) After completing the self-explaining activity, students took a posttest to assessed student conceptual change. The instructor did not provide any feedback to students on their self-explanations before they completed the posttest.

Data Analysis

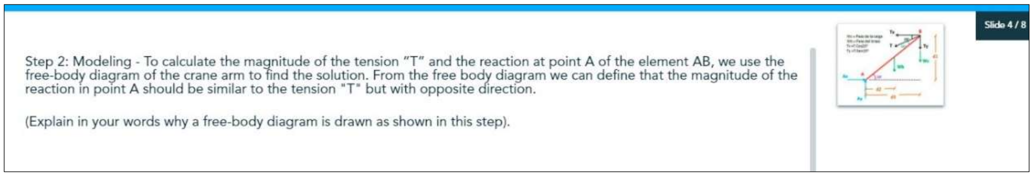
We used descriptive and inferential statistics to identify: i) Changes on students' conceptual understanding and problem-solving skills after working on the self-explanation and spatial visualization activities: paired t-test; and ii) differences on these changes between each self-explaining conditions: complete, incorrect and, incomplete worked-example: ANOVA.



Using the simulator, draw the free-body diagram at points A, B, and C when force F1 is applied.

(a) (b)

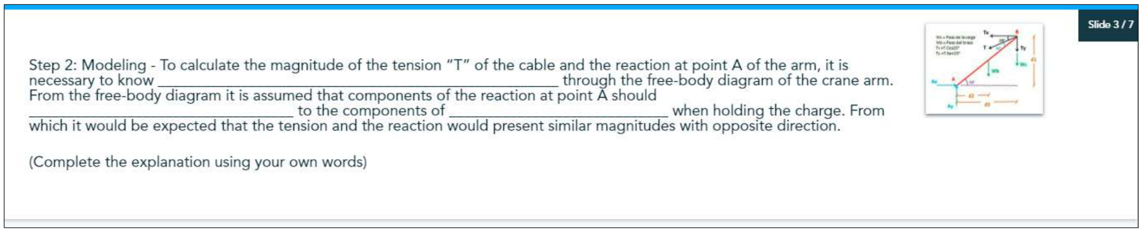
Figure 1. (a). View of *Hapstatics* simulator when is applied an external force in joint B. (b). Activity in *Nearpod* platform.



Step 2: Modeling - To calculate the magnitude of the tension "T" and the reaction at point A of the element AB, we use the free-body diagram of the crane arm to find the solution. From the free body diagram we can define that the magnitude of the reaction in point A should be similar to the tension "T" but with opposite direction.

(Explain in your words why a free-body diagram is drawn as shown in this step).

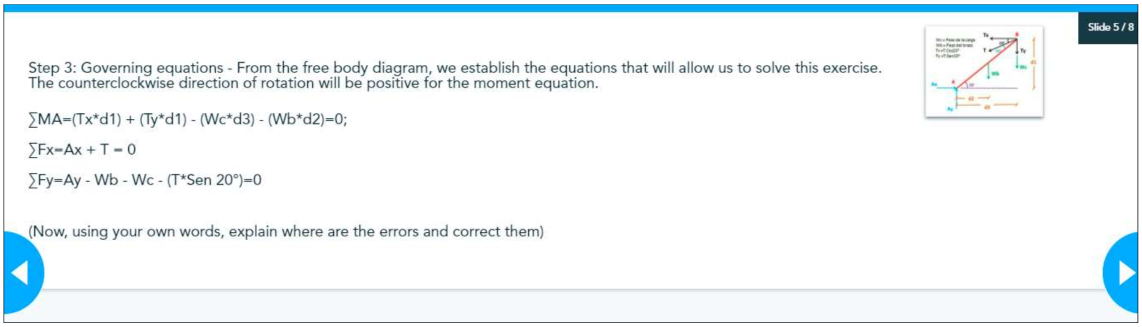
(a)



Step 2: Modeling - To calculate the magnitude of the tension "T" of the cable and the reaction at point A of the arm, it is necessary to know ________________________________ through the free-body diagram of the crane arm. From the free-body diagram it is assumed that components of the reaction at point A should ______________________ to the components of ______________________ when holding the charge. From which it would be expected that the tension and the reaction would present similar magnitudes with opposite direction.

(Complete the explanation using your own words)

(b)



Step 3: Governing equations - From the free body diagram, we establish the equations that will allow us to solve this exercise. The counterclockwise direction of rotation will be positive for the moment equation.

∑MA=(Tx*d1) + (Ty*d1) - (Wc*d3) - (Wb*d2)=0;

∑Fx=Ax + T = 0

∑Fy=Ay - Wb - Wc - (T*Sen 20°)=0

(Now, using your own words, explain where are the errors and correct them)

(c)

Figure 2. Sections of the complete (a), incorrect (b) and incomplete (c) worked-example in *Nearpod* platform.

Results and Discussion

Although the initial number of participating students was 91, some technological issues related to the particularities of remote education limited their participation in the study. Specifically, student internet connection and their limited technological infrastructure became a challenge for some of the students to complete the procedures of this study. In total, 54 students completed all the activities.

Student Conceptual Change

The first step to identify the possible changes in student conceptual understanding after explaining the worked-example, was to assess the difference between the pretest and posttest scores in each example condition. Table 1 depicts the descriptive and inferential statistics for each group (i.e., the case studies). The results show that students in the incorrect and incomplete conditions had a better performance in the posttest than students in the correct condition. The gain was higher for students in the incomplete condition, which changed from an average score of 40.2% in the pretest to 58.8% in the posttest. Note that students in incorrect condition started with an average score of 58.8% in the pretest, which makes it more difficult for them to show a statistically significant gain in the posttest. Likewise the average score for students in the Complete condition was lower in the posttest, this results was not statistically significant. Thus, exploring the complete example did not help or hinder their learning process.

Table 1. Descriptive and inferential statistics of performance test grouped by the example condition.

	Pretest (%)			Posttest (%)			Gain (%)		*t* test			
	Mean	sd	n	Mean	sd	n	Mean	sd	**t*	*df	**p* value	**d*
Correct	40,6	31,6	15	38,6	21,6	15	-2	29	0.26	14	0.79	0.07
Incorrect	58,8	27,2	19	61,6	29,2	19	2,8	21,2	-0.56	18	0.58	0.09
Incomplete	40,2	22,4	20	58,8	27,2	20	18,6	29,6	-2.8	19	0.011	0.74
All	46,8	27,8	54	54,2	27,6	54	7,4	27,6	-1.92	53	0.059	0.2

**t*: test statistics; df: degrees of freedom; *p*-value: probability value; *d*: effect size.

These results suggest that self-explaining incomplete worked-examples support students' conceptual change. Cohen's *d* statistic shows a strong effect size (0,74). Using a one-way analysis of variance (ANOVA), the results suggest that the incomplete condition was more effective than the correct and incorrect condition (F(3,50)=4.945 , *p* value = 0,037).

RQ1: ¿Which of the strategies are most effective for improving students' conceptual knowledge after self-explaining an either correct, incorrect, or incomplete worked-example?

The results suggest that the correct worked-example is not the most appropriate to promote student conceptual change. Having all the elements from the solution available may fail to engage students in actively exploring the examples. This approach results in limited gain from identifying key concepts and strategies to use them in transfer problems. The incorrect worked-example condition demands more effort and additional background knowledge in students to identify the mistakes in the solution, and propose a correct explanation. This condition may be increasing their cognitive load (Grobe & Renkl, 2007; Booth et al., 2013). Incorrect worked-examples may be helpful for students with the required prior knowledge to identify these errors in the examples as evaluating is a higher cognitive skill.

Finally, the incomplete worked-example condition seems to be the most effective strategy to improve conceptual knowledge in Statics students. Explaining each step of the incomplete solution confronted students with the possibility of assimilating new concepts such as restructuring previously conceived ones (Ainsworth & Burcham, 2007). Incomplete examples may be more appropriate for the type of students who usually take a Statics course for the first time: students with considerable conceptual gaps, limited background knowledge and spatial visualization skills (Steif et al., 2010; Litzinger et al. 2010; Haron & Shaharoun, 2010). Incomplete ideas or sentences inside the paragraphs work as a guide for students when trying to fill the blanks in the explanation. This approach focuses students' attention on specific parts of the example, reducing the cognitive load. Self-explaining incomplete worked-examples creates conflicts in deficient mental models, increasing students' awareness of the learning materials. When students do not understand a topic properly, this approach may promote students' conceptual change.

Conclusions, Limitations, and Future Work

This study explored three worked-example formats (i.e., correct, incorrect, and incomplete) together with an interactive visualization tool to promote student conceptual change in a Statics course. The self-explanation strategy allowed students to be more aware of their learning process and develop a stronger conceptual understanding of Statics concepts. The incomplete worked-example generated the most appropriate conditions to promote conceptual change. The integration of visualization tools like the "*Hapstatics*" simulator is essential for students to achieve a deeper understanding of the physical behaviors illustrated in Statics exercises.

The main limitation of this study involves the remote education context, which constrained the sample size, and students' interaction with the Hapstatics tool. This limitation may have influenced students' average score on the pretest for the incorrect condition, significantly higher than for the other two conditions. Future work will focus on the relationship between the quality of students' self-explanations and their conceptual understanding. We will also look into students' interactions with the "*Hapstatics*" simulator and their approaches to self-explain the worked-examples.

References

Ainsworth, S., Burcham, S. (2007). The impact of text coherence on learning by self-explanation. Learning and Instruction, 17, 286-303

Alias, M., Black, T., Gray, D. (2002). Effect of Instructions on Spatial Visualisation Ability in Civil Engineering Students. International Education Journal, 1(3), 1-11.

Booth, J., Lange, K., Koedinger, K., Newton, K. (2013). Using example problems to improve student learning in algebra: Differentiating between correct and incorrect examples. Learning and Instruction, (25), pp. 24-34.

Brown, A., Bransford, J., Ferrara, R., Campione, J. (1983). Learning, remembering and understanding. En J. H. Flavell, & E. M. Markman (Eds.), Handbook of child psychology, 3. Cognitive development (4th ed., pp. 77-166). New York: Wiley.

Chi, M. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), Advances in instructional psychology (pp. 161-238). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

De La Hoz, J. L., Vieira, C., Arteta C. (2020). Promoting Metacognition Skills in Statics Through Self-explanation: A Preliminary Study. In J. van der Veen, N. van Hattum-Janssen, H. Järvinen, T. de Laet & I. ten Dam (Eds.)., Engaging Engineering Education (SEFI) (pp. 1256-1267). University of Twente (online).

Flavell, J. (1976). Metacognitive aspects of problem solving. En: L. B. Resnik (ed.). The nature of intelligence. Hillsdale, N.J.: Erlbaum, 231-235.

Flavell, J., Markman, E. (1983). Handbook of child psychology, 3. Cognitive development. New York: Editorial J. Wiley.

Foutz, T.L., (2019) Using argumentation as a learning strategy to improve student performance in engineering Statics. European Journal of Engineering Education, 44(3), pp. 312-329. DOI: 10.1080/03043797.2018.1488818

Gavelek, J., Raphael, T. (1985). Metacognition, instruction, and questioning, In D. L. Forrest-Pressley, G. Mackinnon, T. Waller (Editors), Metacognition, cognition and human performance. Vol. 2: Instructional Practices. Orlando: Academic Press.

Goodridge, W.H., Villanueva, I., Call, B. J., Valladares, M. M., Wan, N., Green, C. (2014). Cognitive strategies and misconceptions in introductory statics problems. IEEE Frontiers in Education Conference (FIE) Proceedings, 2014, pp. 1-4, doi: 10.1109/FIE.2014.7044346.

Gray, G., Costanzo, F., Plesha M. (2005). Problem solving in statics and dynamics: A proposal for a structured approach. Proceedings of American Society for Engineering Education.

Grobe, C., Renkl, A. (2007). Finding and fixing errors in worked examples: can this foster learning outcomes? Learning & Instruction, (17), pp. 617 - 634.

Haron, N., Shaharoun, A. (2010). Self-Regulated Learning, Students' Understanding and Performance in Engineering Statics. Proc. of the conference Learning Environments and Ecosystems in Engineering Education, Amman, Jordan, pp. 450-459

Khan, S., VanWynsberghe, R. (2008). Cultivating the under-mined: Cross-case analysis as knowledge mobilization. Forum qualitative sozialforschung/forum: Qualitative social research, 9(1), art. 34.

Litzinger, T., Van Meter, P., Firetto, C., Passmore, L., Masters, C., Turns, S.,…Zappe, S. (2010). A Cognitive Study of Problem Solving in Statics. Journal of Engineering Education, 337-353.

McNamara, D., Magliano, J. (2009). Self-explanation and metacognition: The dynamics of reading. In J. D. Hacker, J. Dunlosky, & A. C.Graesser (Eds.), Handbook of metacognition in education (pp. 60–81). Mahwah: Erlbaum.

Montfort, D., Brown, S., Pollock, D., (2009). An Investigation of Students' Conceptual Understanding in Related Sophomore to Graduate - Level Engineering and Mechanics Courses, Journal of Engineering Education, Vol. 98, No. 2, pp. 111-129.

Moore, T., Carling, C. (1982). Understanding language: towards a post-Chomskyan linguistics. London: Macmillan.

Posner, G. J., Strike, K. A., Hewson, P.W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. Science Education, 66(2), 211-227. http://dx.doi.org/10.1002/sce.3730660207.

Schraw, G., Crippen, K.J., Hartley, K. (2006). Promoting Self-Regulation in Science Education: Metacognition as Part of a Broader Perspective on Learning. Research in Science Education, 36, 111–139. DOI: 10.1007/s11165-005-3917-8

Steif, P., (2004). Initial Data from a Statics Concept Inventory. 39th ASEE Midwest Section Meeting in American Society for Engineering Education Annual Conference & Exposition. Proceedings of American Society for Engineering Education, Kansas, USA.

Steif, P., Dollár, A. (2005). Reinventing the Teaching of Statics. Int. J. Engng Ed, 21(4), 723-729.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In R. A. Duschl, & R. J. Hamilton (Eds.), Philosophy of science, cognitive psychology, and educational theory and practice (pp. 147e176). New York: State University of New York Press.

Vieira, C., Magana, A. J., García, R. E., Jana, A., & Krafcik, M. (2018). Integrating Computational Science Tools into a Thermodynamics Course. Journal of Science Education and Technology, 27(4), 322–333. doi:10.1007/s10956-017-9726-9

Walsh, Y., Magana, A., Quintana, J., Krs, V., Silva Coutinho, G., Berger, E., Ngambeki, I., Efendy, E., & Benes, B. (2018). Designing visuohaptic simulations for promoting graphical representations and conceptual understanding of structural analysis. En actas del IEEE-ERM 48th Annual Frontiers in Education (FIE) Conferencia. San Jose, California. Octubre 3-6, 2018.

Yin, R., (2009). Case study research: Design and methods (4ta Ed.). Thousand Oaks, CA: Sage.

Copyright statement