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*Artículos Científicos*

# Innovación basada en metodologías activas para el aprendizaje en la asignatura Pirometalurgia de la Universidad Técnica Federico Santa María, Chile

***Innovation based on active methodologies for learning in the pyrometallurgy course at the Technical University Federico Santa María, Chile***

***Inovação baseada em metodologias ativas para o aprendizado no curso de Pirometalurgia da Universidade Técnica Federico Santa María, Chile***

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**Resumen**

El presente trabajo describe una innovación en la metodología de enseñanza de la asignatura de Pirometalurgia, perteneciente al plan de estudios de la carrera de Ingeniería Civil Metalúrgica y de Materiales de la Universidad Técnica Federico Santa María (UTFSM), Valparaíso, Chile. Los objetivos de la investigación fueron determinar los aspectos más importantes del curso que requerían una intervención metodológica. Esto resulto en una remodelación curricular que era consistente con el modelo educativo declarado por la universidad. Este fue evaluado a través de las percepciones de los estudiantes, una vez las innovaciones fueron implementadas. El modelo educativo UTFSM busca permitir a los estudiantes aprender de su experiencia, permitiéndoles reflexionar y desarrollar una actitud crítica hacia sus acciones y decisiones. En concordancia, las innovaciones implementadas correspondieron a metodologías activas, basadas en el modelo constructivista. los estudiantes —por medio de actividades grupales, reflexión individual, discusión plenaria y uso de software de termodinámica— desarrollaron aprendizajes sobre los efectos de las variables de operación en los procesos de producción de metales. Para el desarrollo e implementación de las estrategias, durante los años 2015 y 2016 (cursos correspondientes a la modalidad de clases magistrales) se efectuaron regularmente encuestas de evaluación docente a los alumnos con pautas autoaplicadas, donde se les pidió expresar sus opiniones sobre su experiencia de aprendizaje. Ellos podían referir críticas, así como mejoras en torno a la metodología, los contenidos del curso y el quehacer docente. Las opiniones consignadas fueron analizadas a través de un análisis del contenido del discurso, dentro de un diseño de investigación cualitativo exploratorio descriptivo y a través de preguntas de carácter cuantitativo. Estas encuestas hicieron posible identificar las necesidades de aprendizaje, acercaron el diseño del curso y la metodología de la evaluación a los estudiantes. Las metodologías activas definidas a partir del análisis de las respuestas dadas por los estudiantes; fueron implementadas durante el primer semestre del año 2019. Esta implementación fue monitoreada con encuestas similares a las usadas en los años 2015 y 2016, donde también se utilizó el análisis del contenido. Los resultados de la presente investigación mostraron que el enfoque innovador del curso; permitió a los estudiantes convertirse en participantes activos en la estructuración de su diseño y metodología. Esto fue consistente con el modelo educativo de la universidad y la racionalización del contenido del curso. Las percepciones de los estudiantes con respecto a la comunicación de los contenidos, el ambiente de enseñanza y el nivel de aprendizaje mejoraron significativamente respecto a los cursos dados con clases magistrales. Los resultados indicaron que las metodologías activas contribuyeron efectivamente a la participación de los estudiantes en clase, promovieron el dialogo en actividades grupales y crearon mejores condiciones de aprendizaje.

**Palabras clave:** innovación metodológica, metodología activa de aprendizaje, modelo constructivista, Pirometalurgia, rediseño de curso.

## Abstract

This paper describes an innovation in the teaching methodology of the pyrometallurgy course, belonging to the curriculum of Metallurgical Civil Engineering and Materials at the Technical University Federico Santa María, Valparaiso, Chile. The objectives of the research were to determine the most important aspects of the course that required methodological intervention. This resulted in a curricular remodeling that was consistent with the educational model declared by the university. This was then evaluated through the students' perceptions, once the innovations were implemented. The UTFSM educational model seeks to allow students to learn from their experience, permitting them to reflect and develop a critical attitude towards their actions and decisions. In concordance, the innovations implemented corresponded to active methodologies, based on the constructivist model. Students through group activities, individual reflection, plenary discussion and use of thermodynamic software developed an understanding about the effects of operation variables on metal production processes. For the development and implementation of the methodologies, - during the years 2015 and 2016 of master classes - teacher evaluation surveys were regularly conducted to students of pyrometallurgy courses with self-applied guidelines, where they were asked to express their opinions on their learning experience. They could refer to criticisms, improvements and suggestions around the methodology, course content and teaching work.

The students' opinions were analyzed through an evaluation of the content of discourse, within a descriptive exploratory qualitative research design and through quantitative questions. These surveys made it possible to identify learning needs, brought the course's design process and assessment methodology closer to students. The active methodologies, defined from the analysis of the responses given by the students, were implemented during the first half of 2019. This implementation was monitored with surveys similar to those used in 2015 and 2016, where content analysis was also utilized. The results of the present investigation showed that the innovative approach of the course allowed for students to become active participants in the structuring it's design and methodology. This was consistent with the educational model of the university and the rationalization of the course content. Student´s perceptions regarding content communication, teaching environment and learning level improved significantly regarding the courses given with the master classes. The results indicated that the active methodologies contributed effectively to the participation of students in class, promoted dialogue in group activities and created better learning conditions.

**Keywords:** methodological innovation, active learning methodology, constructivist model, pyrometallurgy, course redesign.

## Resumo

Este trabalho descreve uma inovação na metodologia de ensino da disciplina de Pyrometallurgy, pertencente ao currículo da carreira de Engenharia Civil Metalúrgica e de Materiais da Universidade Técnica Federico Santa María (UTFSM), Valparaíso, Chile. Os objetivos da pesquisa foram determinar os aspectos mais importantes do curso que exigiam uma intervenção metodológica. Isso resultou em um redesenho curricular consistente com o modelo educacional declarado pela universidade. Isso foi avaliado através da percepção dos alunos, uma vez que as inovações foram implementadas. O modelo educacional da UTFSM busca permitir que os alunos aprendam com sua experiência, permitindo que eles reflitam e desenvolvam uma atitude crítica em relação a suas ações e decisões. De acordo, as inovações implementadas corresponderam a metodologias ativas, baseadas no modelo construtivista. Os alunos - por meio de atividades em grupo, reflexão individual, discussão em plenária e uso de software termodinâmico - desenvolveram aprendizado sobre os efeitos das variáveis operacionais nos processos de produção de metal. Para o desenvolvimento e implementação das estratégias, durante os anos de 2015 e 2016 (cursos correspondentes à modalidade de aulas de mestrado), foram realizadas regularmente pesquisas de avaliação de professores em alunos com diretrizes autoaplicáveis, nas quais foi solicitado que expressassem suas opiniões sobre sua experiência de aprendizagem. Eles poderiam encaminhar críticas, bem como melhorias em torno da metodologia, do conteúdo do curso e do trabalho de ensino. As opiniões registradas foram analisadas por meio da análise do conteúdo do discurso, no delineamento de pesquisa qualitativa exploratória descritiva e por questões de natureza quantitativa. Essas pesquisas possibilitaram identificar necessidades de aprendizagem, aproximaram o desenho do curso e a metodologia de avaliação dos alunos. As metodologias ativas definidas a partir da análise das respostas dadas pelos alunos; Eles foram implementados durante o primeiro semestre de 2019. Essa implementação foi monitorada com pesquisas semelhantes às utilizadas em 2015 e 2016, onde também foi usada a análise de conteúdo. Os resultados da presente investigação mostraram que a abordagem inovadora do curso; permitiu que os alunos se tornassem participantes ativos na estruturação de seu design e metodologia. Isso foi consistente com o modelo educacional da universidade e a racionalização do conteúdo do curso. As percepções dos alunos sobre a comunicação dos conteúdos, o ambiente de ensino e o nível de aprendizagem melhoraram significativamente em comparação aos cursos ministrados nas aulas de mestrado. Os resultados indicaram que metodologias ativas contribuíram efetivamente para a participação dos alunos nas aulas, promoveram o diálogo nas atividades em grupo e criaram melhores condições de aprendizado.

**Palavras-chave:** inovação metodológica, metodologia de aprendizado ativo, modelo construtivista, pirometalurgia, redesenho de curso.

**Fecha Recepción:** Septiembre 2019 **Fecha Aceptación:** Abril 2020

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# Introduction

In the contextual framework of the educational model of the Technical University Federico Santa María (UTFSM) (2015) the following is declared:

> The constant changes and transformations of today's society challenge Higher Education institutions to train comprehensive leaders, professionals and competent graduates, through an educational proposal of excellence that prepares its graduates for the human, scientific, technical and professional fields. What is achieved by developing learning from the students' experience, allowing them to reflect and have a critical conscience regarding their actions and decisions. (p. 12).

This slogan is in tune with the main fundamentals of the constructivist model explained by Ausubel, Novak and Hanesian (1983) and Irzik (2000), according to which the learning process is based on previous knowledge on a given subject, thus as in the external or internal activity that the student carries out in this regard. To facilitate this task, of course, the support that an external agent can provide, which is carried out by the teacher in the formal educational system, is essential. This participation is described in the aforementioned UTFSM educational model as follows:

> Teaching activity is an essential factor in this process, guiding and supporting knowledge management where the role of the student is central. The roles of the teacher, the instructor and the teaching assistant as moderators of the teaching-learning processes are understood; essential actors in permanent improvement, both

in the methodological aspects for teacher training and in its discipline, in order to generate the best conditions for the integral development of students (p. 14).

Now, trying to establish a coherence between classroom pedagogical action and the aforementioned UTFSM educational model, this paper attempts to describe a process of innovation in relation to teaching the Pyrometallurgy Chair with active learning methodologies. The purpose is to ensure that the students of Civil Metallurgical Engineering who take this subject appropriate the thermodynamic concepts necessary to understand, apply and project any change in production processes.

An antecedent focused on the teaching of thermodynamics in the engineering career using active methodologies is the work of Espinoza, Silva and López (2017), who relied on the postulates of significant learning by Ausubel et al. (1983) to positively influence student performance and competence development. According to these authors, this initiative arose because they detected that students in a thermodynamic course of the Industrial Civil Engineering degree had a difficult time applying the knowledge acquired to real problems, that is, they "failed" to use a correct and thorough analysis of situations given in each experiment or situation raised "(Espinoza et al., 2017, p. 3).

The questions posed for the development of this work were the following: is it possible to improve students' perception of the Pyrometallurgy course with the use of active methodologies? Can some active basic science teaching-learning methodologies (eg physics and thermodynamics) be adapted in an applied engineering area such as pyrometallurgy?

The hypothesis proposed was that active learning methodologies can not only be used in the area of pyrometallurgy, but can also positively impact the perception of students regarding the content communication processes, teaching environment and learning level. encouraged in the course.

The objectives set were the following:

a. To determine the most outstanding aspects of the applied course, for which teacher evaluation surveys with self-applied guidelines were used. Some of the questions asked were quantitative in nature, although the opinions of the students were also collected and analyzed through a discourse analysis.
b. Carry out a curricular redesign consistent with the constructivist educational model declared by the UTFSM, for which active teaching / learning methodologies were used.
c. Validate or refute the hypothesis previously raised by evaluating the perception of the students.

# Methodology

## Pyrometallurgy course description

In the graduation profile of the UTFSM civil metallurgical engineer the following is declared:

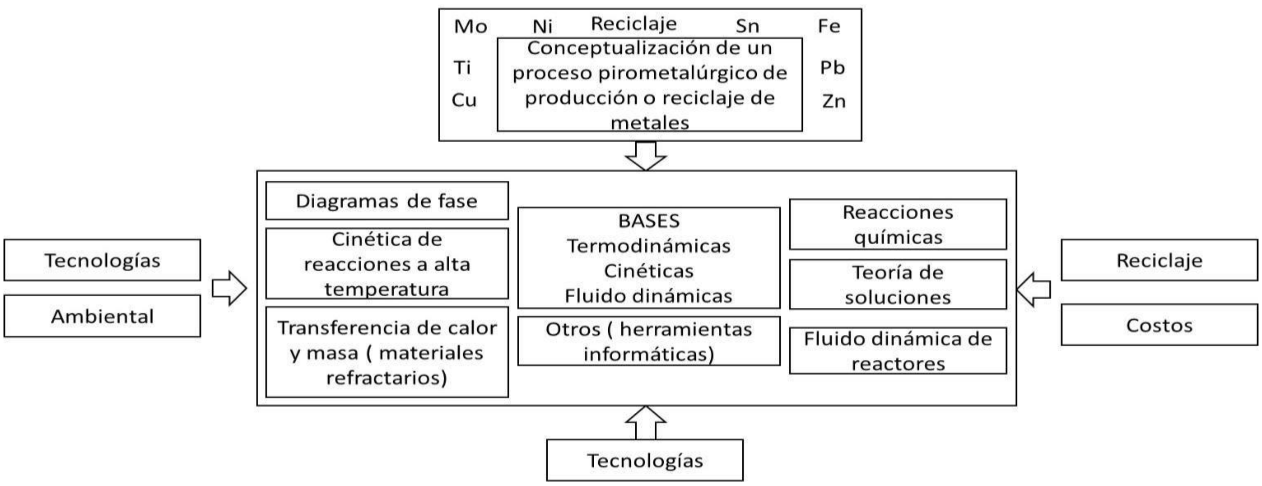
> *The UTFSM Civil Metallurgical Engineer* is a scientifically based professional specializing in metal extraction, processing, application and recycling technologies to meet the needs of industry and society in general. His background in basic science and engineering science allows him to solve equivalent problems in other materials. The field of practice of the profession includes: the operation of industrial facilities and processes; the design and project of process plants; technical support in the commercialization of technologies, products and materials; specialized engineering services; and research and development of new products, processes and applications. In each of these areas, a distinctive set of mathematical, scientific and engineering knowledge is applied to metallurgical problems, in a perspective of sustainable development. To pose and solve problems, combine the use of models, typical of process engineering, with symptomatic diagnosis, typical of materials engineering (UTFSM, 2013, parr 1-3).

The metallurgical civil engineer as a specialist in the transformation of minerals into materials for everyday life has great challenges, among which the following stand out: face innovation with the increasing decrease in minerals, energy and water and develop recyclable materials at low prices that meet the required quality standards without damaging the environment.

In this context, this paper describes a teaching process based on active methodologies for the subject Pyrometallurgy., Which is taught in the ninth semester of the curriculum of the Civil Engineering Metallurgy and Materials career (UTFSM, 2017, p . 4). The number of students taking this subject is usually between 20 and 30 people, who must have passed subjects such as Fluid Mechanics, Metallurgical Thermodynamics I and II, Heat Transfer, and Kinetics and Design of Metallurgical Reactors.

The thematic contents of Pyrometallurgy can be represented according to the scheme indicated in figure 1. This chair is related to the production and recycling of metals, among which copper, nickel, lead and zinc can be mentioned. Pyrometallurgical processes are based on basic engineering sciences such as thermodynamics, kinetics, and fluodynamics. During classes, an attempt is made to promote a learning interaction between pyrometallurgical processes and thermodynamic concepts, where metallurgical processes are assimilated by means of these concepts. The reason for the processes is understood through the use of phase diagrams related to the partial pressures of the gases (oxygen, sulfur, arsenic) present in the chemical reactions of the cases analyzed. Likewise, specific application elements are included —such as the theory of solutions and others more indicated in figure 1— that allow energy, environmental and other evaluations to be carried out. The course is designed for a total of 166 hours per semester, of which 66 are considered as non-contact work that the student must complete.

**Figura 1.** Diagrama secuencial de los contenidos del curso de Pirometalurgia




Fuente: Elaboración propia

## Teacher evaluation surveys 2015, 2016

As an integral part of the course and of this research, during the years 2015 and 2016, teacher evaluation surveys with self-applied guidelines were regularly carried out in which students were asked to write their opinions about the learning experience. In these surveys they could refer criticisms, improvements and suggestions regarding the methodology, course content and teaching tasks. The answers were examined by analyzing the content of the discourse, a methodology developed by authors such as Bardin (2002), Salgado (2007), Touraine (2012) and Valdivia (2008), who describe the application of this method mainly in educational research related to the social sciences and the areas of health, although it is worth noting that this procedure can also be used in the sciences of physics and chemistry.

In 2015, 23 students participated, while in 2016, 25. They also registered 105 sentences corresponding to the linguistic universe analyzed. To elaborate the categories and estimate their importance, frequencies of the sentences contained in the opinions were made, which were grouped into the following four categories: improvements regarding the support material, improvements related to the instructions and class activities, relative improvements to the teacher's explanation and pedagogical qualities, and methodological suggestions.

### Improvements around the support material: 13 sentences

Regarding the support material used in the keynote talks using power point, the participants indicated that improvements should be made around the design and its use. Regarding the design, they pointed out that the support material lacked order, hence they recommended that it be reworked to be used as later study material.

### Improvements related to instructions and activities: 26 sentences

Some mentions were linked to the quality of the activities. They highlighted the value that was given to the processes translated into diagrams and exercises, in addition to the detail with which the parameters were treated. The way of evaluating and the work carried out were positively weighted. In this category, the speech referred to a low level of instruction, and not its absence. Likewise, favoring order was explained in the explanations given.

Regarding the proposed activities, they suggested a better coordination of the assistantships, laboratories and classes through a proposed schedule from the beginning of the semester. They also recommended further teacher guidance to those performing the assistantships to contribute more effectively to the course objectives. In addition, focus the assistantships on optimizing the students' prior preparation for the competitions and strengthening the exercises with numerical calculation.

### Improvements to the teacher's explanation and pedagogical qualities: 26 sentences

The students pointed out that the teacher made adequate and pertinent explanations with the task. They highlighted the handling of the subject and the mastery of content along with the ability to transmit them. By demonstrating specific mastery of complex concepts, motivation for the course was encouraged.

Likewise, they expressed that there was a receptive attitude to the doubts of the students, both in the classroom and outside it. They also noted that the teacher was willing to answer questions at all times. They highlighted the willingness of the teacher and his interest for the student to learn. Finally, the participants considered that teamwork and research were enhanced.

The students, however, thought that the teacher could improve the closing of classes, with more explicit conclusions, written on the board. Parallel to the analysis of thermodynamic variables of the cases studied in class, the teacher could develop numerical calculations that represent these analyzes.

## Methodological suggestions: 40 sentences

The highest frequency of sentences referred to improvements around the methodological proposal. In this regard, they pointed out that the dynamics of the class could be modified, increased and changed in focus. They also recommended placing more emphasis on mathematical analysis, as well as further exemplification of cases. Likewise, clarification of the evaluation system was requested.

Regarding the methodology, they indicated more discussion with the participation of the entire course, and not separately. In addition, they indicated the need to review the excessive time spent reviewing tutorials and the need to approach real situations through exercises and industrial examples and to schedule visits to a foundry. They also mentioned that feedback should be made on contests and errors in the execution of tutorials, as well as improving the order in the presentation of information. In addition, they suggested more course planning and leveling out thermodynamics knowledge at the beginning of the course.

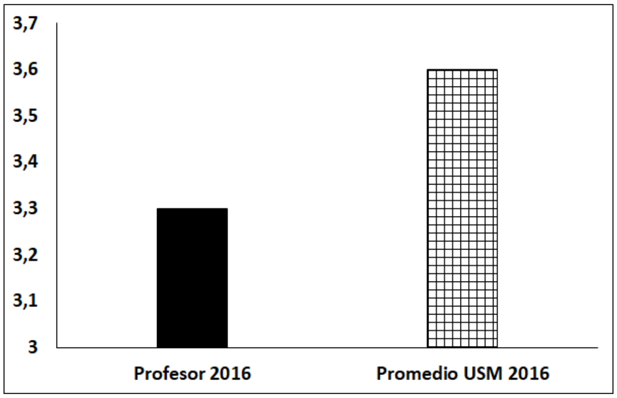
On the other hand, there were aspects of the methodology that were positively weighted, such was the case of the tutorials and the talks. They explained that the information was delivered sequentially and logically, and indicated that during the course the contents were complemented and through the tutorials the learning was made explicit.

## Discussion about the teacher evaluation surveys 2016

The methodological innovation described in this work sought to expose the weaknesses, manage the strengths and the proposals indicated by the students in the teaching evaluation and intervene the course with elements that allow a constructivist teaching and learning process.

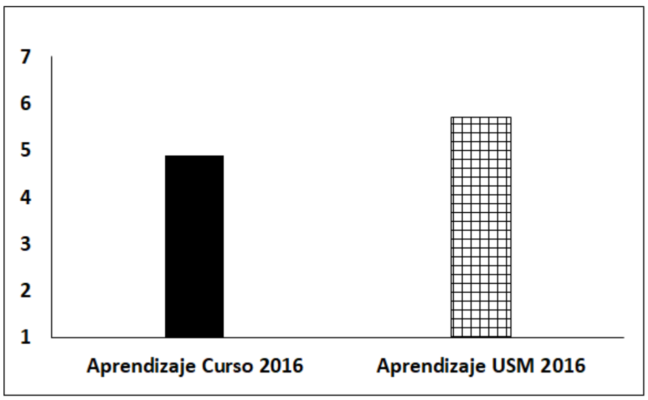
The results of the quantitative surveys of the 2016 academic year (it is worth clarifying that in 2015 no questions of this nature were asked) allowed us to detect some deficiencies regarding the course. For the teacher evaluation, a scale of 0 to 4 was used (in this range 3 was considered to be a poor grade), it is shown in figure 2. The level of learning achieved by the students was classified from 1 to 7 ( a rating of 4.5 was estimated as deficient), it is shown in figure 3. In summary, it can be said that the Pyrometallurgy course had a result substantially below the average of the total UTFSM.

**Figura 2.** Evaluación docente 2016




Fuente: Elaboración propia

**Figura 3**. Nivel de aprendizaje 2016




Fuente: Elaboración propia

From the analysis of the surveys, the following were selected as intervention activities: rethink the keynote talks, redesign the didactics of each specific topic, innovate in the design of the didactic sequence of each class and rethink the evaluation system. This meant a substantial change in the teaching method. Next, it is indicated how the course was intervened according to the previous points.

# Redesign of the course in methodology and evaluation with a constructivist approach

## Rethinking of the keynote talks

The purpose of this intervention activity was to move from an information transmission scheme to one with active teaching methods (Mills and Treagust, 2003), as indicated in Table 1. Emphasis was made in designing the course to help the student to learn differently from the traditional method, which focuses on the transmission of knowledge (Mazur, 2009). The objective of the talks was to promote conceptual conflicts that allow the student to conceptualize the processes from new perspectives (Hewson y Beckett, 1984).

**Tabla 1.** Comparación de los dos métodos de enseñanza

| **Método anterior** | **Método actual** |
|---|---|
| Énfasis: qué enseñar y qué libro usar. | Énfasis: Cómo enseñar, en especial cómo ayudar a los estudiantes a aprender. |
| Presentaciones para entregar información (transmisión de información). | Curso basado en técnicas de aprendizaje y enseñanza activos.<br>Promover el pensamiento en términos de conceptos básicos (termodinámica, cinética y fluohidrodinámica).<br>Énfasis en el uso de herramientas de simulación y casos de estudio. |
| Enseñanza basada en presentaciones. | Enseñanza basada en debate y trabajos grupales. |
| Amplia cobertura de temas-baja comprensión. | Menos cubrimiento de temas-alta comprensión.<br>Presentación breve de los tópicos. |

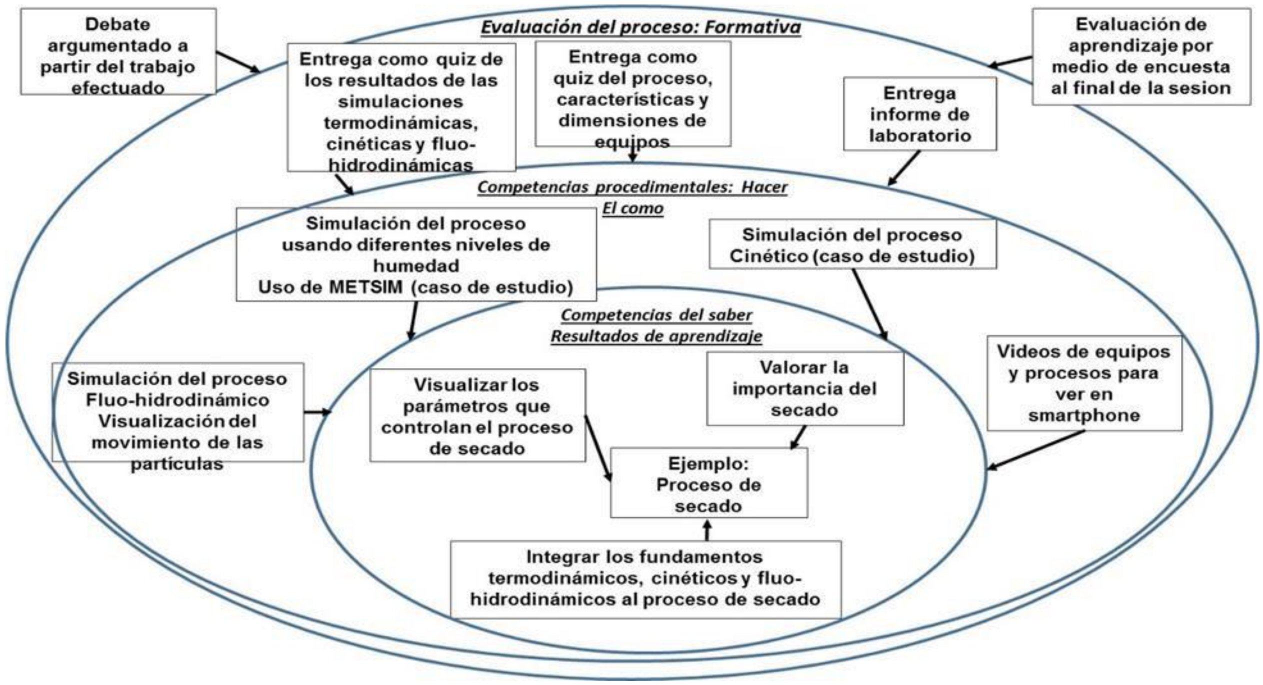
Fuente: Elaboración propia

## Redesign of the didactics of each specific topic

In figure 4, the didactics designed using three concentric circles that indicate the sequence to teach of a specific topic (drying) are outlined. The first circle indicates the evidence of performance that can be achieved in learning outcomes (RdA); the second refers to the tools that must be used to achieve the learning results, and the third the evaluation method. The simulation tools were the support for the how (Lewis and Linn, 2003), for which commercial simulation programs were used. The simulation was associated with comparing the processes with different input parameters as case studies. The results of these simulations will allow, in part, the argumentation argued in results

(Martini and Hartzell, 2015). Externally, additional factors to evaluate the success or deficiencies of the teaching and learning process are indicated.

**Figura 4.** Diseño didáctico de un tópico específico

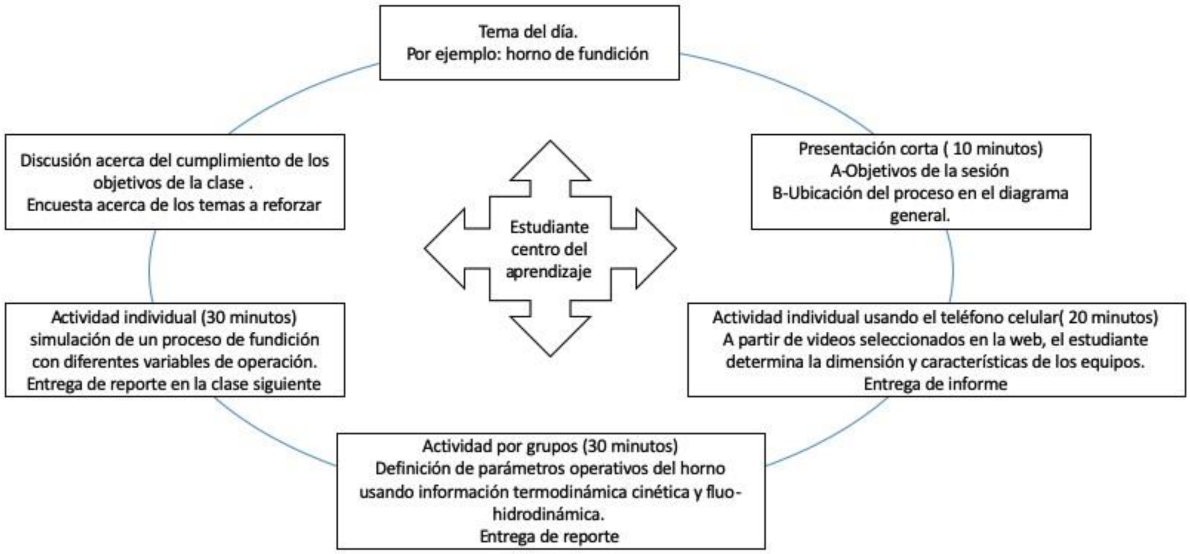



Fuente: Elaboración propia

## Innovation in the design of the didactic sequence of each class

Consonant with the above, methodological innovations were made through didactic planning. This consisted of proposing active learning activities, such as debate and the integration of technologies as support tools for learning. In the classroom, the session lasted an hour and a half (two sessions per week). The didactic sequence of a session is indicated in figure 5, where it is observed how the interventions of master presentations do not last more than 10 minutes and the activities are carried out for the most part by students through simulation work: use of thermodynamic information to discover the why of the processes (Hewson and Beckett, 1984), argued group discussion based on the results of simulation and use of technological elements as an integral part to describe the processes.

**Figura 5**. Secuencia didáctica de una sesión

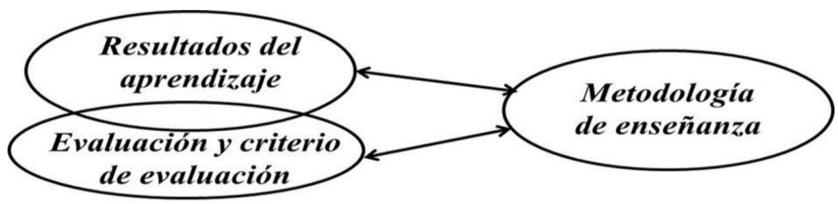



Fuente: Elaboración propia

## Rethinking of the evaluation system

For the design of this innovation, consistency was sought among the three components of the curriculum design (Cowan and Cherry, 2012), as indicated in figure 6.

**Figura 6.** Interacción entre los tres componentes principales del diseño de un curso




Fuente: Cowan y Cherry (2012)

The fundamental principle was to ensure that the three components were designed to answer the following three questions:

1. 1. What assessments and what assessment criteria will you use to show that students have achieved learning outcomes? This was addressed by a participatory assessment of students from all classes along with permanent feedback of results. Also, this included the socialization of plans to implement improvements.
2. What teaching methods will you use to achieve those learning outcomes?

3. What do you want your student to learn? For this, the exit profile declared by the department was taken into account, which indicates, among other aspects, the following:

- Apply the basic sciences and engineering sciences that underpin metallurgical engineering.
- Communicate with other people orally and in writing.
- Participate as a member and later as a driver in work teams.
- Also, as learning outcomes, the student is expected to achieve the following:
- Apply the theoretical foundations used in pyrometallurgical processes.
- Acquire basic knowledge of the unit processes used in pyrometallurgy.
- Correlate each unit process by describing the general process.
- Transfer a specific process to another, applying industry procedures.
- Analyze energy consumption and environmental impacts, considering them in the production and recycling chain.

The summative and formative evaluations are shown in Table 2, which includes the contribution to the graduation profile of the Department of Metallurgical and Materials Engineering (UTFSM, 2013). These evaluations are expected to address the interaction indicated in Figure 4 and the learning outcomes plotted.

**Tabla 2.** Plan de evaluación formativa y sumativa de la asignatura

| Evaluación del curso | Peso | Contribución al perfil de egreso |
|---|---|---|
| **Académica** | | |
| 1-Tutoriales total = 7; valor de cada tutorial 2 puntos | **15** | **1, 2** |
| 2-Balance de masa y energía (reporte del HSC) trabajo acumulado durante el semestre | **15** | **1, 2, 3** |
| 3-Lectura, reporte y presentación de un documento (cinco minutos de presentación) | **10** | **1, 2** |
| 4- Construcción e interpretación de diagramas de fase ternario de uso en la pirometalurgia (trabajo en grupo) | **10** | **1, 2, 3** |
| 5- Certamen intermedio (nota mínima 40 en una escala de 100) | **15** | **1** |
| 6-Certamen final (nota mínima 50 en una escala de 100) | **15** | **1** |
| Total | **80** | |
| **Laboratorios** | | |
| Reportes de laboratorio | **20** | **1, 2, 3** |

Fuente: Elaboración propia

# Results

## Implementation of educational innovations in the first semester 2019

The innovations implemented were evaluated at the end of each class, including three questions in which students were asked to briefly write down their opinions on the following:

1. What the instructor did especially well during class.
2. What the student believed should be improved.
3. What you learned.

In total, 23 students participated, respectively, who wrote a total of 129 sentences. The following were the defined categories, although it is worth noting that some similar responses may appear in different categories.

### Suggested improvements to the methodology: 31 sentences

As for the study material, they proposed to increase the study of real industrial situations to facilitate learning, as well as to increase the class dynamics through the discussion of topics with more reflective questions and greater individual and collective participation. They also recommended increasing educational support material (videos, slides, phase diagrams, and tutorials were mentioned in this category). It is worth commenting that there were difficulties with the links offered to access the videos, so they suggested that these should be delivered before class or provide the name to search for them on the Web. In addition, they mentioned that the slide scheme and the study of phase diagrams should be maintained. Regarding the tutorials, they proposed that a more detailed explanation should be offered on how to do them and establish a delivery schedule.

Regarding the methodology used, they considered that it should not proceed so slowly, so the time for the conceptual explanation should be increased. Likewise, at the end of the group discussion, the teacher should finish with a conclusion and go deeper into what has been learned through exercises with numerical calculations, and not only with the analysis of the thermodynamic variables of the pyrometallurgical processes.

### Suggested improvements to the teacher's explanation and pedagogical qualities: 51 sentences

The presence of phrases around clear and concise explanations of the teacher about concepts was significant (adequate use of time, content explained in a striking way, dynamically developed classes that created a pleasant learning environment). In other words, order and good content were appreciated in the presentations with didactic explanations, hence it was inferred that the transmission of the information was effective and that the interaction was adequately promoted. In addition to this, the use of the videos was a very illustrative resource.

The teacher generated discussion spaces based on real problems in industrial processes and promoted critical thinking in students to seek explanations. He also encouraged them to express their opinions and interact with peers. He guided the groups to obtain their own answers and increased the dynamics of the discussions by asking more questions to deepen the students' level of knowledge. In short, the teacher served as a moderator (not as someone who only dictates subject matter).

The suggestions for improvements, however, focused on the fact that the teacher could offer a summary on the board of the concepts and considerations that the students should understand and make of the thermodynamic variables (in the case studies of pyrometallurgical processes treated in class ), as well as their numerical calculations.

### Referred learning level: 47 sentences

The students' response to the referred learning focused on the importance of graph analysis for the construction of knowledge about the world copper market. Another specific aspect was the generation of awareness about the environmental damage caused by elements that are part of pyrometallurgical processes such as arsenic.

On the other hand, although more generally, it was appreciated that a learning interaction between pyrometallurgical processes and thermodynamic concepts had been achieved during classes, an essential aspect to assimilate metallurgical processes. In fact, the pyrometallurgical processes were understood through graphs (phase diagrams) related to thermodynamics. In addition, they indicated that the reason for the processes was understood through the use of phase diagrams related to the partial pressures of the gases (oxygen, sulfur, arsenic) present in the proposed chemical reactions.

## Final survey of the course in the first semester 2019

At the end of the semester, a final survey was applied in which 15 students participated; The same three questions from the survey described above were included in this and were analyzed in the same way.

### Positive aspects of the educational experience: 48 sentences

The students' responses were classified according to the methodological changes indicated in Table 1. Regarding the criteria of how to teach, the participants considered that the course was well designed and organized, according to the order in which the processes are studied (started sequentially from the easiest to the most complex), and believed that the classes were practical and didactic.

Regarding the course based on active learning and teaching techniques and promoting thinking in terms of basic concepts, the students felt that the contents were explained with many examples, practical, experimental and simulation demonstrations, which served to analyze and deepen the thermodynamic aspects involved in the pyrometallurgical processes studied. The labs were a good addition to the course. They considered that a clear relationship was established between thermodynamics and pyrometallurgy processes. They also stated that they learned to relate copper extraction processes with those of other minerals, as well as theoretical and / or experimental ternary and binary phase diagrams with practice. In addition, they understood the importance of the control of parameters in each process depending on what was sought to obtain.

Regarding debate-based teaching and group work, the opinions of the students included that the course encouraged collaborative work through analysis of study material in groups. The employed method, in addition, allowed them to pose interesting questions to delve into the content.

**Improvements related to the educational experience: 27 sentences**

The responses of the students to the educational improvements have been classified in this section taking into account the didactic design on the knowledge and procedural competences, as well as the formative evaluation indicated in figure 4. Regarding the knowledge competences, the students suggested that the course should include a review of thermodynamic concepts during the first two class sessions. According to their perceptions, the course would have to be complemented with a class session on theoretical foundations and dedicate the following session to the study of processes and consultations. In addition to this, they considered that in each class what could be analyzed in the studied processes could be established. Likewise, they proposed to extend the study topics for pyrometallurgical processes that are not linked to copper and to complement the course with field trips.

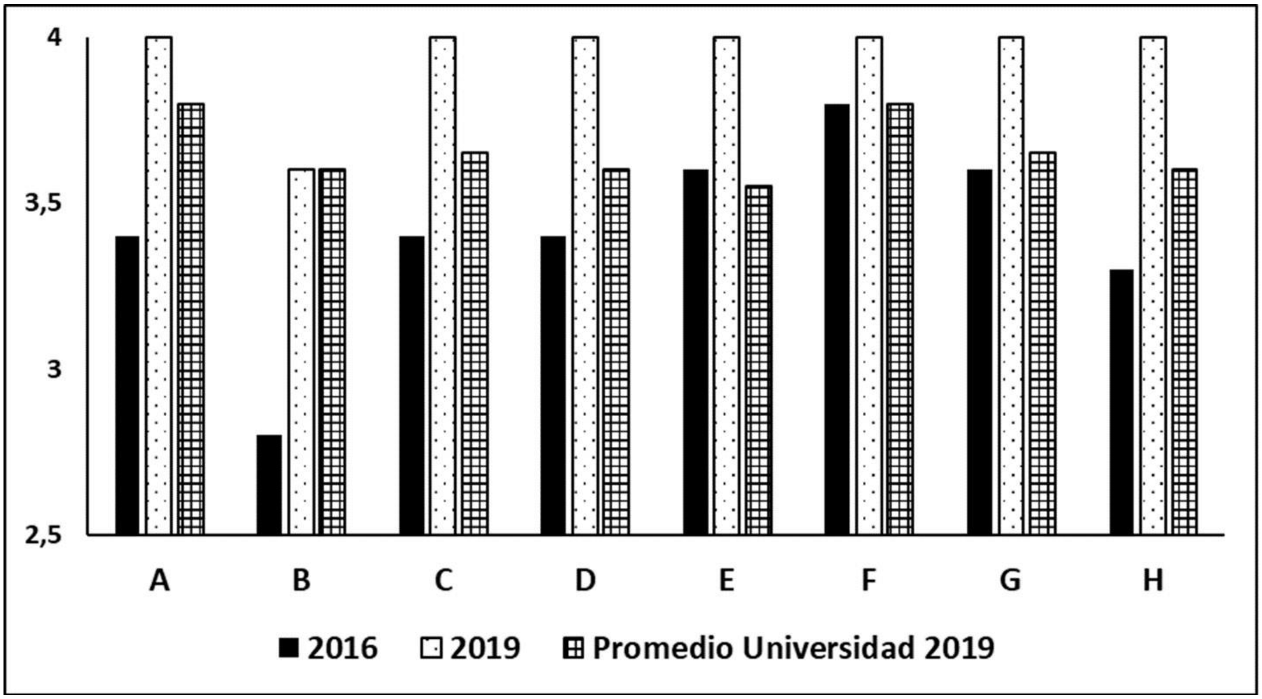
Regarding procedural competencies, they indicated that the guides used as class work material should be delivered individually, and not in groups. They also considered that time was wasted in searching for the videos and that there was a gap between the different reproductions. Therefore, they agreed that the videos should be presented for the entire group, and not individually reviewed on the cell phone.

Regarding the evaluation of the process, they pointed out that when the analysis of a process concluded, the teacher could explain on the board the conclusions obtained and increase the calculations in the analyzed processes. In addition, they indicated that the course required a lot of extra class study time, so they recommended increasing the assigned credits.

## Comparison of the teaching evaluation of the Pyrometallurgy course between 2016 and 2019

Next, figure 7 shows a comparison regarding the content management and pedagogical skills of the teacher during the Pyrometallurgy course taught at the UTFSM in 2016 and 2019. The questions were evaluated quantitatively on a scale of 0 to 4 (a rating of 3 is considered very low).

**Figura 7.** Evaluación docente en cuanto al manejo de contenidos y habilidades pedagógicas (años 2016 y 2019)




Fuente: Elaboración propia

Table 3 shows those related to content management and pedagogical skills. It is worth clarifying that the same teacher was in charge of the courses of 2015, 2016 and 2019. In the study it was considered that the difference in the grades obtained between the years 2016 and 2019 corresponds mainly to the teaching-learning method used.

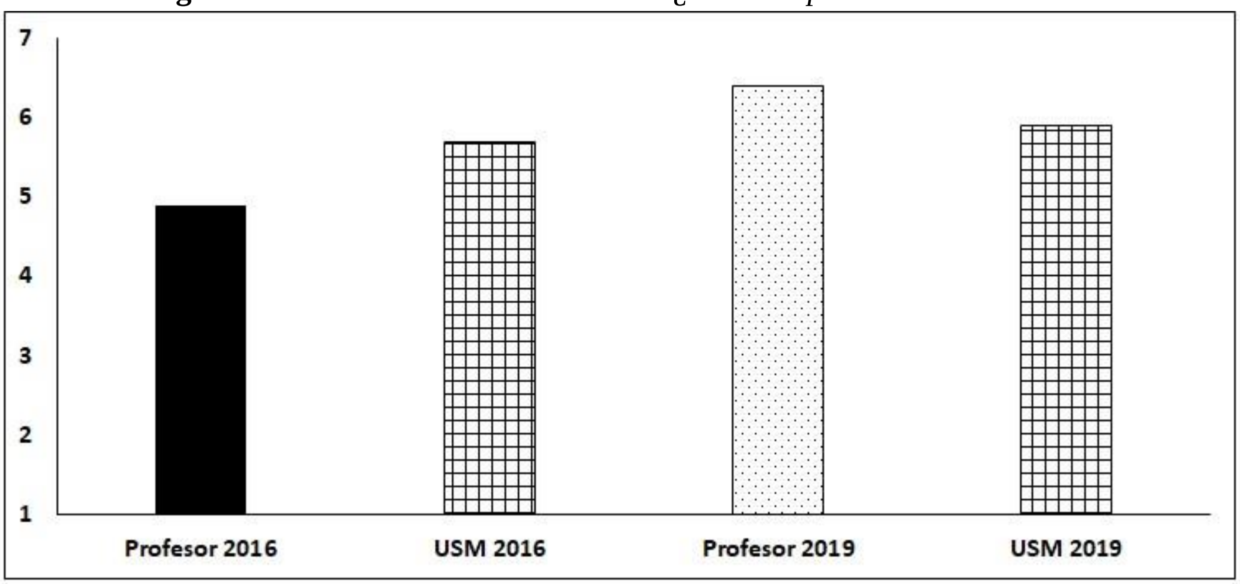
**Tabla 3**. Preguntas de manejo de contenidos y habilidades pedagógicas (años 2016 y 2019)

| **Pregunta** | **Contenido** |
|---|---|
| A | Mostró dominio de los temas del curso. |
| B | Transmitió los contenidos del curso de forma clara y compresible. |
| C | Creó un ambiente favorable del curso en el aprendizaje. |
| D | Estimuló la participación activa de los estudiantes en las clases. |
| E | Promovió el diálogo entre los estudiantes. |
| F | Fue respetuoso con los estudiantes. |
| G | Estuvo abierto a recibir críticas y sugerencias de los estudiantes. |
| H | Mostró compromiso con el proceso de aprendizaje. |
| I | ¿Cuánto aprendiste en el curso? |

Fuente: Elaboración propia

Figure 8 shows a better grade of students on the teaching work in the 2019 school year compared to 2016. This can be attributed to the implementation of the educational interventions used and discussed earlier in the course. In addition, it can be seen that the teacher's teaching evaluation in 2019 exceeds the average value obtained for UTFSM teachers in this year.

**Figura 8.** Resultados en torno al criterio *¿Cuánto aprendiste en el curso?*

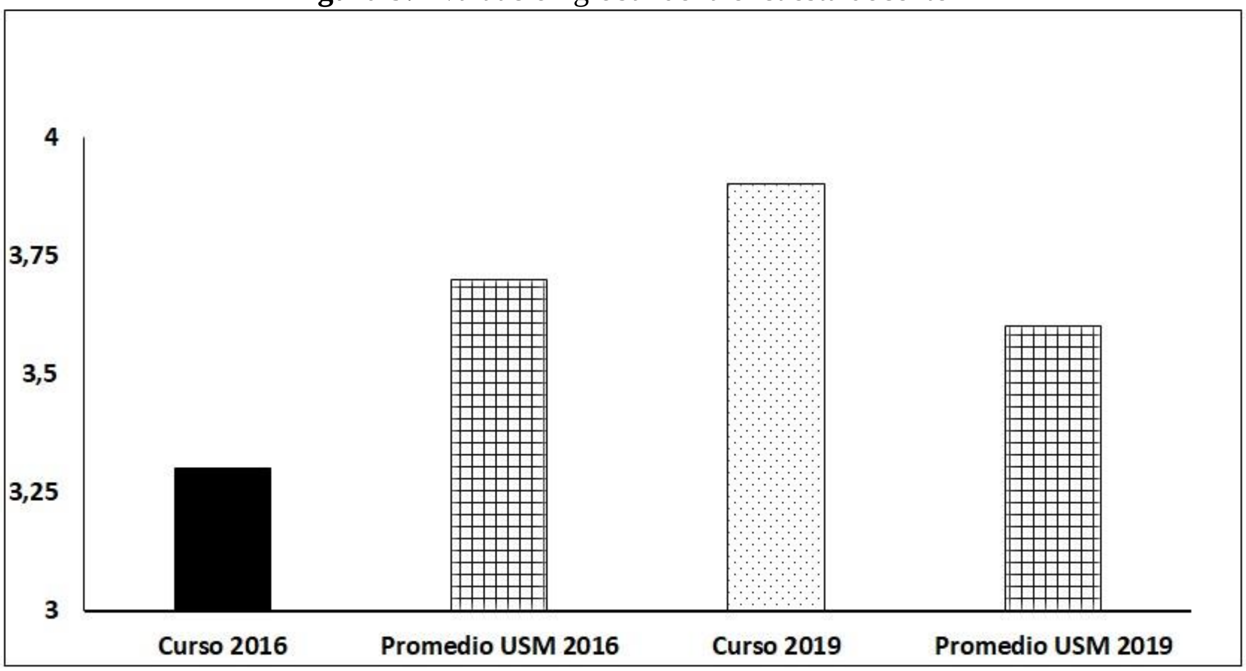



Fuente: Elaboración propia

Figure 9 shows the global teaching evaluation consisting of three questions: content management and pedagogical skills, teacher-student relationship and formal aspects (years 2016 and 2019) and the average teacher evaluation of the UTFSM courses in these years (it is clarified that under the category of formal aspects the teacher is classified in the following aspects: compliance with the planned activities, attendance to classes regularly and punctually, correct distribution of course time, use of clear and explicit evaluation criteria, evaluations adjusted to the activities developed, delivery of grades within the established deadlines and preparation of classes).

The 2019 Pyrometallurgy course was better evaluated than the average value of the UTFSM courses. It is interesting to note that no question in the quantitative survey was weighted below 4, contrary to 2016 where approximately 15% of the students considered each of the questions to be deficient (less than 4).

**Figura 9**. Evaluación global de la encuesta docente




Fuente: Elaboración propia

# Discussion

The hypothesis of the present work stated that active learning methodologies would positively impact students' perception of the course. Considering that a redesign in methodology and evaluation was carried out with a constructivist approach, the results of the investigation clearly indicate that this hypothesis could be corroborated. According to what was expressed by the students in the opinion polls, the changes applied in the Pyrometallurgy course improved the communication of the contents, the teaching environment and the level of learning.

Likewise, it is possible to infer that the strategies used are capable of being used in areas other than the basic sciences. The results shown in figure 6 confirm that the active methodology of the 2019 Pyrometallurgy course, compared to the master methodology of the same course in 2015 and 2016, contributed more effectively to the participation of students in class, promoted the dialogue of students in group activities and created better learning conditions.

The objectives set for the development of the research included the analysis of the content of discourse of information collected through surveys. This was accomplished and was effective for the curriculum redesign and its implementation. The surveys in each class of the 2019 course provided relevant information to redirect the course methodology in order to positively influence student learning. A strength of this methodological innovation lies in the fact that it was the students who built their own learning methodology, according to the opinions recorded in the surveys of the years 2015, 2016 and 2019.

The theoretical and practical contributions investigated in the bibliographic review were useful in the development of the research objectives. For example, the discourse content analyzes developed by Bardin (2002) were used to define the most relevant aspects to intervene in the course and in the validation of the hypothesis. Discussions regarding the constructivist method of Hewson and Beckett (1984) and Irzik (2000) allowed to define a constructivist discourse conceptually in the planning of the course. The bibliographic review of authors such as Espinoza et al. (2017) and Manzur (2009) contributed to the practical implementation of the active methodologies. Finally, the works of Cowan and Cherry (2012) favored the development and implementation of the course evaluation system.

As for the limitations to implement the method, there were logistical difficulties such as an inadequate provision of classrooms. The lighting, ventilation and sound insulation system did not contribute to maintaining the best working conditions. In some classes, the rooms did not have round tables and mobile blackboards to facilitate group work. Furthermore, course assistants, a basic pillar in group discussions, lacked the training and experience to participate in active methodologies courses.

The experimental redesign did not include a control group due to the small number of students per year (between 20 and 30). This would have allowed in a same period a direct comparison of the innovations implemented. Therefore, the study is limited to comparing the results between different years where the course was assigned to the same teacher.

For subsequent studies, however, a standard summative evaluation should be considered, as this would allow a quantitative comparison of the achievements in the learning objectives between the courses taught in the years 2015 and 2016 (master class) and 2019 (class of methodologies). active).

The work, on the other hand, did not elaborate a psychological profile of the students at the beginning of the course. The results could contribute to detecting students with difficulties to accept group work and define teaching-learning strategies accordingly. These analyzes will be used in subsequent studies to delve into the improvements in the implementation of the methodologies.

Currently, the use of active methodologies declared by the UTFSM as an educational model has already been implemented in some physics courses. It has been the resistance of both teachers and students to change traditional teaching methods that has not allowed its extensive use. It is considered that this experience in the Pyrometallurgy 2019 course can be successfully expanded to the hydrometallurgy and mineral processing courses that are part of the curriculum of the civil metallurgical engineer of the UTFSM.

## Conclusions

The innovation in the teaching methodology of the subject Pyrometallurgy, through active methodologies, is described as a process that begins with the identification of needs for learning the core concepts and teachings of the field. This resulted in didactic planning and instructional design that guide a paradigmatic transit, not only methodological and technical.

The innovation contemplated the opinions of the students in the identification of needs for learning, as well as for didactic planning and the design of activities. The above was supported by an exploratory descriptive qualitative methodological design, which gave a systematic and scientific approach to what the students referred to, in such a way that it allowed the elaboration of categories that guided the aforementioned design.

The innovation associated with the didactic sequence in the classroom and the activities they involve turned out to be possible to implement in the time provided for the class and according to planning. Through the content of the speech, the students pondered and criticized the group activities, the teacher's explanations, the plenary discussion, the individual simulation activities and the material review.

The methodological innovation developed has been based on the UTFSM educational model that recognizes constructivism as the axis in the understanding of teaching and learning methods. Our innovation brought the design processes and methodological evaluation closer to the students, being consistent with the educational model and the rationality that emerges from it.

The innovation implemented realizes that learning occurs in a social environment, in interaction with peers and in a relationship with the teacher. The latter is decisive in learning not only because of the mastery of formal knowledge of the discipline, but also because of the good treatment, consideration and recognition towards those who seek and try to build knowledge, that is, their students. According to the experience obtained in the development of this research, accompanied by careful planning of the course, active teaching-learning methodologies require flat teacher-student power relations for their implementation and, therefore, pedagogical skills different from those used in the master classes.

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