Multidisciplinary Teaching of Variable Complex Functions in Heat Flow Systems

EDUARDO GAGO, PAOLA SZEKIETA, LUCAS D'ALESSANDRO
Computer and Multidisciplinary Laboratory of Basic Sciences,
Universidad Tecnológica Nacional, Facultad Regional Rosario,
Zeballos 1341,
ARGENTINA

Abstract: - In the context of new curriculum designs in engineering careers, new lines of work are being developed in teaching to achieve the development of basic competencies, acquisition of skills, and the replacement of old learning paradigms with new didactic techniques that are currently applicable. These characteristics in teaching are consolidated when they are added to the integration of knowledge in the teaching-learning process and the inclusion of computer resources. In the present work, the use of new pedagogical methodologies and diverse didactic strategies has been implemented, aiming at multidisciplinary work in the development of the topic of Complex Variable Functions corresponding to the Advanced Calculus subject in the Mechanical Engineering program. The didactic proposal presented corresponds to a system related to heat transfer in an incompressible fluid, where the concepts of complex field and fluid flow are approached analytically and graphically, giving meaning to the curricular contents, and facilitating the interpretation and conceptualization of the theory.

Key-Words: - Multidisciplinary Teaching, learning, complex variable, heat flow, laboratory, simulation, models.

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1 Introduction

The new challenges posed on Engineering Education, supported by government organism-established guidelines, for the accreditation of degree programs, highlight the need for multidisciplinary training of the student.

This multidisciplinary training is supported by the implementation of learning proposals, that involve the application of computer resources.

All universities appear to share a common goal, that is, to ensure the appropriate education of students which will allow them to play an active, ethical, and responsible role in the complex society of today, [1].

The recommendations made by accreditation agencies urge students to engage in learning activities using computational tools. This proposal aims to move away from the traditional classroom setting by proposing a methodological strategy supported by a new perspective of competency-based teaching.

University students must be prepared to make decisions and effectively deal with the challenges posed by a globalized, technological society, respecting the rights of individuals and safeguarding the legacy to be left to future generations, [1].

It is intended that the student acquires knowledge through an experimentation process, using simulation and visualization. To achieve this, the student must formulate working hypotheses, induce responses, question predictions, and validate them to give meaning to the learning process.

It is possible to highlight a set of essential minimum contents for the basic training of the engineer, which are being addressed in the Advanced Calculus subject.

Advanced Calculus subject is taught at the third level of the Mechanical Engineering program.

This paper recounts several classroom experiences undertaken on that subject.

In the last decades the voice of the student has been rarely taken into consideration. Today's competitive market structure determines a shift in higher education organisational focus towards the needs and wants of its main actor/consumer. Student satisfaction is increasingly associated with institutional success. The antecendet of student satisfaction is service quality. Thus, service quality needs further attention, especially in new offers by assessing as accurtaely as possible the features that attract students or that are requested by them, [2].

The teaching-learning process is implemented through the integration of various disciplines within the program, which requires the teacher to know about the teaching programs of other parallel subjects, not only those of the Integrator Core but also of basic and specialty subjects.

Until not many years ago, it was common for research on the teaching-learning of any area of knowledge, including mathematics, to focus on cognitive processes, or how a student can capture, encode, store, and work with the information that is normally transferred to him or her by the teacher. But in this process, other factors also influence, such as motivational, affective, metacognitive, evolutionary, and social factors, which can have their importance in the context of education, [3].

As a final goal in educational work, it is necessary to organize coordinated practices to link basic and simple problems of the subject with the problematic situations that develop in Fluid Mechanics and Heat Transfer.

2 Motivation and Objectives

The multidisciplinary teaching approach aims to relate the content and concepts taught in class to real Engineering projects.

In this way, the objective of the class is to provide future engineering professional with the necessary tools to detect relevant variables in a problem, and interpret and propose solutions to different alternatives, thus increasing their analytical capacity.

The rational selection of teaching proposals and perspectives is based on decision-making by students based on the solutions found, [2].

Since the topics are related to current problems actually present in the actuarial sector, undertaking the projects is a very stimulating way to get familiar with the sector context and required skills for a professional, [4].

The didactic activities proposed consist of emphasizing theoretical research by the students with the teacher's guidelines, followed by making an analogy of the physical parameters of the topic under study. Finally, with the gathered information, solve the proposed problematic situation using technological resources.

The methodological proposal for presenting mathematical content is based on the search for models that simulate a simple situation in the Engineering field, [5], [6].

Formulating the technical situation in mathematical terms involves presenting a simplified scenario translating that situation into mathematical terminology, and working with that model.

After a critical review, a list of different aspects to be changed/improved (as well as those to keep) is proposed for each of the analyzed degrees in order to incorporate the most appropriate evaluative and methodological features to help in the achievement of specific, generic and basic skills of each degree, [7].

This methodology stimulates interest in discovery and fosters confidence in the use of the formative aspects of mathematics, related to other areas of knowledge, such as in this case, the analysis of the dynamics of a specific fluid.

. These characteristics in teaching are consolidated when they are added to the integration of knowledge in the teaching-learning process and the inclusion of computer resources.

The pedagogical objectives are outlined in the following phases:

- Presentation of the system to be analyzed.
- Theoretical research.
- Parameter modeling and analysis
- Interpretation of results in technical terms.

Mathematical competence formation in university students is a pedagogical process that takes place in several stages. According to the formation logic in Mathematics academic discipline, the formation of mathematical competence in university students requires a stage that depends on the motivational objective, [8].

Mathematical competence formation effectiveness in university students depends on certain pedagogical conditions. In our study, we identified the following pedagogical conditions in teaching mathematics: Formation of a stable motivation for teaching mathematics; use of personal developmental techniques; and designing the content of the discipline.

The first condition for the formation of mathematical competencies in university students is the formation of a stable motivation for teaching mathematics. Focusing on this condition is one of the most important features enabling the future specialist to realize the role of mathematics in his professional activity, [8].

This problem is especially acute at present, when students, are firstly guided by the study of subjects measured by their professional significance and increased competitiveness in the labor market. The choice of the second condition is due to the personal component of the methodological approach to teaching.

Developmental techniques used in education are of personality-oriented education importance for potential activities implementation, [8].

3 Methodology

Learning based on the development of simple, integrative, and ideal projects is a methodology that enables students to acquire key basic knowledge and skills through the presentation of models that address specialty-specific problems.

But without being necessary to arrive at concepts that we can qualify as a high level of development, Mathematics is present in all degrees in Engineering in any university in the world.

Normally, the subjects of Mathematics are placed in the first years of these degrees. And it is here that from the consortium we have formed, we see that Mathematics and its associated subjects are fundamental elements of engineering education, and proficiency in the area is expected.

Engineers are required to be analytical and be able to utilize their mathematical toolkit to solve problems that may be ill or well-defined depending on the contextual situation of the engineer. Until quite recently the determination of learning was undertaken using face-to-face techniques such as handwritten assessments, private and public communication, and observation to name but a few.

Assessment and program delivery underwent a seed change with the new millennium when Educational Authorities and Professional bodies adapted their validation and accreditation methods to include learning outcomes within programs of study.

The assessment techniques within programs altered accordingly to address these requirements and forces have evolved within higher education to increase the online presence, [3].

The role of teachers in this teaching implementation approach is to act as guides, and facilitators of the teaching-learning process, and to provide support throughout the experiences.

In addition to coordinating a series of multidisciplinary activities that result in a continuous collaboration task, strengthening the project, [9].

The classroom experience takes place in the Basic Sciences Multidisciplinary Computer Laboratory, a learning space with 25 networked computers and a small library.

The laboratory notebook is a common tool used in research areas such as Biology, Biochemistry, Chemistry, and Mathematics.

It is therefore interesting that students learn in the laboratory how to work with it. Since the first-year laboratory experiments, students use it and it is also an item for the assessment.

All the measurements, computations, and results, as well as the incidences that occurred during the experiment, have to be written there.

We consider that the laboratory notebook helps stud students to neatly save/report the results and the experiences that happened during the laboratory lessons [7].

The specific resources and methodology applied in each case are different as the objectives pursued are also different. Nevertheless, there are some points in common. Special emphasis has been placed on the use of the recommended textbooks, because a worrying decline in using them has been observed in most students in the last courses, [10].

4 Theoretical Foundations

The systems being analyzed correspond to heat flow in a region of the complex plane of a fluid

First, it is proposed to analyze the heat flow around a cylinder with a circular cross-sectional area, followed by a second activity, where the heat flow is analyzed knowing the stream function as data.

4.1 Fourier's Law of Heat Conduction (Molecular energy transport)

Heat conduction in fluids can be thought of as molecular energy transport, inasmuch as the basic mechanism is the motion of the constituent molecules.

Energy can also be transported by the bulk motion of a fluid, and this is referred to as convective energy transport; this form of transport depends on the density of the fluid. Another mechanism is that of diffusive energy transport, which occurs in mixtures that are interdiffusing, [11].

A medium heat conductor is considered when a temperature distribution may be variating.

The Fourier law of heat conduction allows us to calculate the amount of heat conducted per unit area in a unit of time through a surrounding medium. This quantity is called the heat flow through the surrounding medium, and is given by:

$$Q = -K\,\nabla T \qquad (1)$$

In equation (1), Q is heat flow; ∇T is the complex temperature gradient, and K is a constant, known as thermal conductivity which depends on the material or medium through which it is diffusing.

That is, the rate of heat flow per unit area is proportional to the temperature decrease over the distance.

Equation (1) is also valid if a liquid or gas is placed between the two plates, provided that suitable precautions are taken to eliminate convection and radiation, [10], [11].

Actually Equation (1) is not a law of nature, but rather a suggestion, which has proven to be a very useful empiricism. However, it does have a theoretical basis.

If the temperature varies in all three directions, then we can write an equation like equation (1) for each of the coordinate directions, [10], [11]:

$$q_x = -K\frac{\partial t}{\partial x};\ q_y = -K\frac{\partial t}{\partial y};\ q_z = -K\frac{\partial t}{\partial z} \qquad (2)$$

If each of these equations (2) is multiplied by the appropriate unit vector and the equations are then added, we get the equation (1) which is the three-dimensional form of Fourier's law.

This equation describes the molecular transport of heat in isotropic media. By isotropic we mean that the material has no preferred direction, so that heat is conducted with the same thermal conductivity K in all directions, [11].

The problems designed for students to solve in class serve as a vehicle for conceptualizing the topic of complex variable applications when the heat flow meets the following conditions:

- The fluid flow is two-dimensional: The basic fluid model and the characteristics of fluid motion in a plane are essentially the same in every parallel plane.
- The flow is steady or uniform: The fluid velocity in a determinate point of the plane depends only on the (x, y) position and not on time.
- The fluid is incomprehensible: The density is constant.
- The fluid is non-viscous: It has no viscosity or internal friction in the fluid layers, [12].

4.2 Modelling of the System under Study

After conducting theoretical research on the fundamental concepts of heat transfer in fluids, students will identify the variables involved in the system under study.

With regards to the interest shown by students to solve problematic situations, which will then be described, enounces:

If temperature T is a complex variable function, whose independent variable is a complex number Z, such that:

$$z = x + j\,y \qquad (3)$$

where x is the real part of z, y is the imaginary part of z, and j is the imaginary unit.

Variable z can be represented graphically in a coordinate rectangular system called Argand Diagram. However, the x, y and $f(z) = T$ values can not be plotted on a single set of axes, as can be done with real functions of a real variable.

T is known as analytic in a region R of the complex plane z, if $T'(z)$ a derivative exists in every z point of R [12], [13].

The complex temperature T is composed of the ordered pair whose real part is the temperature potential t and the imaginary part is the stream function w.

$$T(x, y) = t(x, y) + j\,w(x, y) \qquad (4)$$

A necessary condition for T to be analytic in a region R of the plane z is that t and w in R satisfy the equations expressed in (5), called the Cauchy-Riemann equations:

$$\begin{cases} \dfrac{\partial t}{\partial x} = \dfrac{\partial w}{\partial y} \\ \dfrac{\partial t}{\partial y} = -\dfrac{\partial w}{\partial x} \end{cases} \qquad (5)$$

If these partial derivatives are continuous in R, so the equations (5) are sufficient conditions for T to be analytic in R. Functions that satisfy these conditions are called conjugate and harmonic functions.

The conjugate and harmonic functions fulfil the following properties:

a) The family of the curves, for all α and β real numbers, expressed in equations (6) are orthogonal.

$$\begin{cases} T(x, y) = \alpha \quad (\forall\, \alpha \in R) \\ w(x, y) = \beta \quad (\forall\, \beta \in R) \end{cases} \qquad (6)$$

b) If, in addition, the second partial derivatives of t and w exist and are continuous in R, the Laplace equation is satisfied. For t and w, the Laplace equations are as shown in (7), [13], [14].

$$\begin{cases} \dfrac{\partial^2 t}{\partial x^2} + \dfrac{\partial^2 t}{\partial y^2} = 0 \\ \dfrac{\partial^2 w}{\partial x^2} + \dfrac{\partial^2 w}{\partial y^2} = 0 \end{cases} \qquad (7)$$

If the analysis of heat flow is limited to a two-dimensional model, then the quantity of heat for such a model is:

$$Q = -K\left(\frac{\partial t}{\partial x} + j\,\frac{\partial t}{\partial y}\right) \tag{8}$$

The magnitude of the heat quantity, also referred to as the heat flow velocity, is calculated as the modulus of the complex quantity expressed in equation (8).

$$|Q| = K\sqrt{\left(\frac{\partial t}{\partial x}\right)^2 + \left(\frac{\partial t}{\partial y}\right)^2} \tag{9}$$

Where,

$$\begin{cases} q_x = -K\dfrac{\partial t}{\partial x} \\ q_y = -K\dfrac{\partial t}{\partial y} \end{cases} \tag{10}$$

Whatever C may be, represents a simple closed curve in the complex plane z, delineating the boundary of the cross-sectional area of a cylinder, and assuming q_t and q_n denote the normal and tangential components of the heat flow, respectively, with steady-state conditions ensuring no net heat accumulation within C, then the following holds [12].

$$\begin{cases} \int_C q_n\,dS = \int_C q_x\,dS - \int_C q_y\,dS \\ \int_C q_t\,dS = \int_C q_x\,dS + \int_C q_y\,dS \end{cases} \tag{11}$$

If is not any heat accumulation within C, that means heat accumulation is null, this situation is represented in (12).

$$\begin{cases} \int_C q_n\,dS = 0 \\ \int_C q_t\,dS = 0 \end{cases} \tag{12}$$

Assuming there are no sources or sinks within C. The equation (8) can be expressed in the form of education [11], [14].

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \tag{13}$$

5 Learning Space

A teaching sequence is designed with a theoretical-practical-technological approach. Three classes of three clock hours each are implemented to carry out the proposed activity.

The class, which is called theoretical-practical-technological, is a class that does not separate theory from practical activities and takes place in a computer-mediated mathematics laboratory.

In Laboratory Class, students work in groups of no more than three members. For this purpose, two cases are presented for students to solve with the support of computer tools.

Each student has the freedom to choose their group partners according to their preferences, but the only established indispensable condition is teamwork.

Each group has, at least, a desktop computer to work but also, it is allowed for the students to bring their personal computers for the task development.

In pedagogical science and practice, new approaches and methods for solving the problem of improving professionalism are constantly being developed. Some of them are based on the use of new information technologies in the training of qualified specialists, others are focused on updating the content of professional training, and several of them are interested in strengthening practical orientation, [15].

The characteristics of this class are to establish the guidelines of a interactive task of Engineering analysis, resulting in an activity that generates new ideas.

In these cases, it is common for students to replicate what they have seen in class, without a clear idea of why or what for, and without knowing very well what to do in the case of small variations in the types of problems posed in class. We could say that the students have learned the concepts, but only to apply them in situations equal to those created by the teacher. This is one of the reasons why the contents may lack real meaning for these students. Likewise, there are places in which results are prioritized without concern for the mental processes that the student develops when solving mathematical exercises or problems, [3].

This teaching methodology enables to advance in a learning system, where the student assumes an active role and allow them to build concepts through experimentation and the development of conclusions.

For the implementation of project based learning in the curricula of engineering degree programs lecturers' instructional abilities are critically important as they take on increased responsibilities in addition to the presentation of knowledge, [16].

Eduardo Gago,
Paola Szekieta, Lucas D'Alessandro

5.1 Analysis of Heat Flow around a Circular Cross-Sectional Cylinder

The first activity presented to students consists to analyse the heat flow around a circular cylinder with adiabatic walls. For this purpose, the complex temperature function is provided to them as data, with its law being:

$$.F(z) = A\left(z + \frac{k}{z}\right) \qquad (14)$$

where A and k are two positive constants.

As a guide for the development of the activity, the following questions are posed to the students:

a) What relationships can be established between the potential temperature t and the stream function w?
b) What are the equations that model the isotherms and the heat flow lines of the system?
c) What is the graphical representation of the trajectories of the isotherms and the heat flow lines?
d) What is the physical interpretation of the parameters, plotted in the previous point?
e) What is the temperature profile at different points along its trajectory?
f) What are the system stationary points?
g) What equation measures the heat amount at all points of z plane?
h) What happens if in the heat flow the cylinder has an elliptical transversal cross?
i) What happens if the heat flow is not confined to a adiabatic wall cylinder, and there is a sink on point $0 + j\,0$?

The students answer the previous questions, with the teacher collaboration, arriving to the following conclusions:

The t and w functions, fulfil with te Cauchy-Riemman equations, and consequentially with Laplace equation, confirming that both functions are conjugate and harmonics.

. The student determinates the line equations of the isotherms and the heat flow lines through the computational tools application.

The result obtained by MATHEMATICA software in the calculus of t and w is presented:

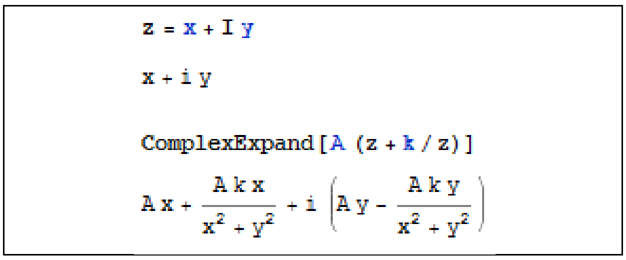

Fig. 1: Student work with the software

The data provided by the software about the heat flow and the isotherms are respectively showed in the equation system (15).

$$\begin{cases} A\,y - \dfrac{A\,k\,y}{x^2 + y^2} = \beta \quad (\forall\, \beta \in R) \\ A\,y + \dfrac{A\,k\,x}{x^2 + y^2} = \alpha \quad (\forall\, \alpha \in R) \end{cases} \qquad (15)$$

In Figure 1 is observed that the isotherms are been plotted with line points and are orthogonal to the heat flow line, which are plotted with a continuous line.

Far from point $0 + j\,0$ (coordinate origin), observing the graphic from Figure 2, the heat flow lines are parallel to axis x, When we are approximating to coordinate origin, the heat flow lines presents a curve than reach near the y axis, surround the cylinder centred in the origin filed in that region.

These curves indicate the trajectory the heat flow follows in that region of z plane. When $w = 0$, the graph of the heat flow lines shows a tangent line parallel to the x axis, with a null slope.

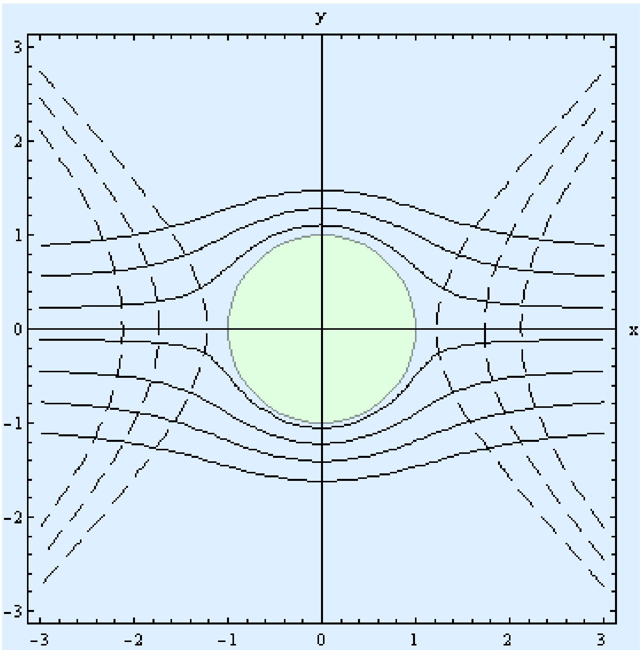

Fig. 2: Heat flow and isotherm curves

In maths, graphics with the characteristics that presents the isotherms and heat flow are called contour lines. The contour lines have the characteristic that they do not intersect each other.

```
ComplexExpand[A (z + k / z)]
```

$$Ax + \frac{Akx}{x^2 + y^2} + i\left(Ay - \frac{Aky}{x^2 + y^2}\right)$$

```
g[x_, y_] = A x + A k x / (x^2 + y^2)
```

$$Ax + \frac{Akx}{x^2 + y^2}$$

```
D[g[x, y], x]          D[g[x, y], y]
```

$$A - \frac{2Akx^2}{(x^2 + y^2)^2} + \frac{Ak}{x^2 + y^2} \qquad -\frac{2Akxy}{(x^2 + y^2)^2}$$

```
Sqrt[(D[g[x, y], x])^2 + (D[g[x, y], y])^2]
```

$$\sqrt{\frac{A^2\left(k^2 - 2k\left(x^2 - y^2\right) + \left(x^2 + y^2\right)^2\right)}{\left(x^2 + y^2\right)^2}}$$

Fig. 3: Student computer work with the software

The software enables students to develop a operation sequence to calculate the fluid velocity circulation in each point of Complex Plane z, using the versatility that the computational resources provides.

Use of technology made it possible to make more explicit the role of modes of representation. In particular, the way in which the complementarity between graphic, numerical and symbolic representation, produce best comprehension using technology and help develop coordination processes.Thus, the descriptions of the construction process followed by students have allowed relating aspects of the particularization to the reflective abstraction derived from the modes of representation in construction knowledge. These early educational experiences continued with intervention and interaction activities with students, inside and outside the laboratory, through virtual platforms, always favoring the approach and requests, [2].

Computers have become nowadays a valuable tool for Education The animation of figures and representations, achieved by using the proper software, develop the students' imagination and enhance their problem-solving skills. In the forthcoming era of the Fourth Industrial Revolution computers will provide, through the advanced Internet of Things (IoT), a wealth of information for students and teachers, [17].

According to procedure observed in Figure 3 the students determine that function that governs the heat amount in a two dimensional fluid in the Complex plane z is:

$$Q = A\sqrt{1 + \frac{k^2 - 2k(x^2 - y^2)}{(x^2 + y^2)^2}} \qquad (16)$$

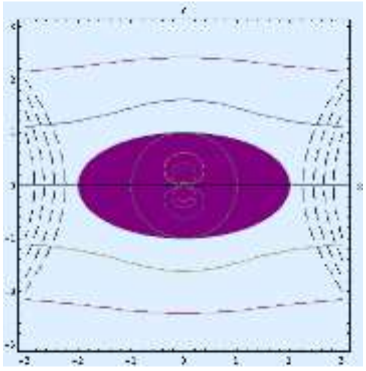

Fig. 4: Heat flow and isotherm curves

If an observer at the origin moves away from the obstacle the amount of heat has its maximum value, $Q = A$, the amount of heat tends to a constant value as the observer moves away from the obstacle.

The stationary system points are those where the velocity is null, and in this case are given by the values of $z = \sqrt{k}$ and $z = -\sqrt{k}$.

In Figure 4 and Figure 5, the simulation of two alternative situations from the original is observed.

From Figure 4, it can be determined that when the given heat flow encounters an elliptical cross-sectional cylinder, it is observed that the flow lines have a wider separation, while the isotherms are closer to each other compared to the circular cross-sectional cylinder.

Also, a new simulation is made, consists in supress the cylinder and considers a sink in the coordinate origin.

This change modifies the heat flow, determining that if one is away from the origin, it behaves the same as any cylinder, but at the coordinate origin, the heat dissipates through the sink. Figure 5 illustrates this situation.

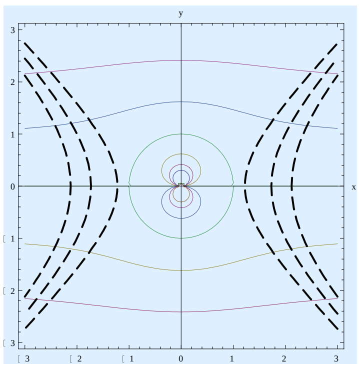

Fig. 5: Heat flow and isotherm curves

5.2 Analysis of Heat Flow Known Current Function

In this opportunity, it is analyzed the function stream current w, in a heat transmitter system.

The announced data in equation (17) is the law that determines the stream function:

$$w(x,y) = -A\ arctg\left(\frac{2ky}{x^2+y^2-k^2}\right) \qquad (17)$$

Where A and k are two positive constant.
The following questions are posed to the students:

a) What is the potential temperature t related to w?
b) What are the heat flow lines and isotherms equations?
c) What is the graphical representation of the above trajectories and how can they be physically interpreted?
d) What is the temperature profile at different points along the fluid path?
e) What are the stationary points of the system associated with equation (17)?
f) What is the equation that measures the amount of heat at all points in the z plane?

According to previous questions, the students arriving to the following conclusions for this case:

The steps that were made with the software to obtain the potential temperature are detailed in Figure 6.

```
u[x_, y_] = -A ArcTan[2 k y / (x^2 + y^2 - k^2)]

-A ArcTan[2 k y / (-k^2 + x^2 + y^2)]

Integrate[f[x, y], y] // TrigToExp

1/2 A Log[-(k^2 - 2 k x + x^2 + y^2)/(k^2 + 2 k x + x^2 + y^2)]
```

Fig. 6: Student work with computer tools

According to the works with computational tools, the potential temperature t obtained is:

$$t(x,y) = \frac{1}{2}A\ ln\left(\frac{(x+k)^2+y^2}{(x-k)^2+y^2}\right) \qquad (18)$$

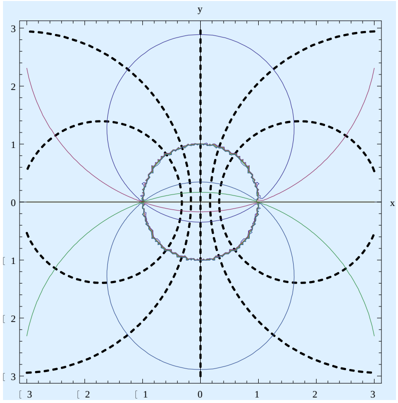

Fig. 7: Heat flow and isotherms curves

The Equations (19), and (20) represents the expressions of heat flow lines and isotherms, and are respectively:

$$-A\ arctg\left(\frac{2ky}{x^2+y^2-k^2}\right) = \alpha\ \ (\forall\ \alpha \in R) \qquad (19)$$

$$\frac{1}{2}A\ ln\left(\frac{(x+k)^2+y^2}{(x-k)^2+y^2}\right) = \beta \quad (\forall\ \beta \in R) \qquad (20)$$

Figure 7 shows that the heat flow lines are logarithmic spirals entering at the origin, and the current lines are two families of orthogonal circles, and have similarities to the field lines of a magnet with the poles located at two points in the complex z plane of coordinates $k + j0$ and $-k + j0$.

Implementation of technology in teaching has now become a trend of the modern world. Specifically, in the field of mathematics, ICT is bringing day by day a positive motivation in the learning process by fostering and encouraging interaction between students, by stimulating them with quick feedback focusing on solution strategies as well as interpretation of the final solution. This implementation supports the constructive theory of pedagogy to apply and deepen ideas, [18].

6 Conclusion

The approach to multidisciplinary activities in Mathematics from the Basic Sciences in Engineering careers, through the exploration of new knowledge and pedagogical methods, fosters creativity through the analysis and management of simple mathematical models, resulting in an innovative teaching-learning process.

To achieve the theoretical conceptualization of the abstract contents of complex variable functions, it is essential to be able to mathematically analyze the heat transmission system presented to the students. This proposal is a motivating approach that allows the integration of theory, practice, and technology, making this activity a challenge for future research.

In the experience presented in this paper, the creation of a dynamic and symbolic information space is an important contribution to engineering education, introducing a new paradigm in the teaching of sciences.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Eduardo Gago: Implementation and development of the classroom experience. Application of mathematical, computational, or other formal techniques to analyze or synthesize study data. Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection. Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation). Management and coordination responsibility for the research activity planning and execution. Management and coordination responsibility for the research activity planning and execution.
- Paola Szekieta: Development of the classroom experience. Development or design of methodology; creation of models. Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs.
- Lucas D'Alessandro: Development of the classroom experience.Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs.for the Statistics.

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The authors have no conflicts of interest to declare.