

# Sketching STEM: A Hands-On Guide on Drawing-to-Learn Approaches





# Sketching STEM: A Hands-On Guide on Drawing-to-Learn Approaches

INTRODUCTION:	005
WHY THIS BOOK AND HOW TO USE IT	
<i>Paulo Luís Almeida &amp; Mário Bismarck</i>	

## PART I

# Preparing the ground

01.	LEARNING BY HAND: AN OVERVIEW OF LEARNER-GENERATED DRAWING WORKSHOPS	015
	<i>Maria Catarina Silva, Paulo Luís Almeida &amp; Mário Bismarck</i>	
02.	WARM-UP GAMES: HOW TO OBSERVE YOUR OWN PERCEPTION	
	PAYING ATTENTION TO CONTEXT: THE NEGATIVE SPACES	020
	<i>Cláudia Amandi</i>	
	VISUAL-MOTOR SYNCHRONICITY: BLIND DRAWING APPROACHES	022
	<i>Jorge Marques</i>	
	THE TOUCHING EYE: HAPTIC VISUALITY	024
	<i>Paulo Luís Almeida</i>	
	REMEMBER: EXERCISES ON MEMORY	026
	<i>Cláudia Amandi</i>	

## PART II

# The Workshops

## OBJECTS AND STRUCTURES

1.	POLARISING ATTENTION: DRAWING UNDER THE MICROSCOPE	031
	<i>Paulo Luís Almeida &amp; Mário Bismarck</i>	
2.	TACTILE DRAWING: MANIPULATION AS A PROCESS OF ANALYSIS AND REPRESENTATION IN OSTEOLOGY	049
	<i>Marina Vale Guedes</i>	

## PROCESSES

3. DRAWING METABOLIC MAPS: SIMPLIFYING COMPLEXITY 065  
*Marina Vale Guedes, Maria Strecht Almeida, Isabel Cardoso, Ana Magalhães, Paulo Luís Almeida, Mário Bismarck*
4. THE VISUALISATION OF INTEROCEPTION: 075  
DRAWING THE FEELINGS AND SENSATIONS  
THAT WE HAVE INSIDE US  
*Garry Barker*
5. DRAWINGS AND REPRESENTATIONS FOR ENTROPY 089  
*Jorge Marques, Cláudia Amandi, Orfeu Bertolami, João Horta Belo, José Ramalheira Vaz*

## RELATIONSHIPS

6. DRAWING BEYOND THE PLANE: 107  
EXPLORING RIGHT-ANGLED TRIANGLES  
IN SPHERICAL GEOMETRY  
*Helena Mena Matos, Vasco Cardoso & Pedro Alegria*
7. MAPPING TERRITORIES: 123  
DRAWING AND REPRESENTATION OF SPACE  
*Sílvia Simões, Pedro Alegria & Flávia Costa*
8. PUTTING MAPS INTO PERSPECTIVE: 137  
DRAWING TERRITORY AND LANDSCAPE IN GEOGRAPHY  
*Vasco Cardoso, Luís Espinheira, David Lopes*

ACKNOWLEDGEMENTS 152

REFERENCES AND FURTHER READING 154

# Putting maps into perspective: Drawing territory and landscape in geography

Vasco Cardoso<sup>1</sup>,  
Luís Espinheira<sup>1</sup>,  
David Lopes<sup>1</sup>

## SUMMARY

The workshop was designed for the *Master in Teaching Geography in the 3<sup>rd</sup> Cycle of Basic Education and Secondary Education* students at the Faculty of Arts and Humanities of the University of Porto and aimed at future geography teachers. The objective was to create a context-specific geographic knowledge of the landscape through drawing.

The proposed problem was: How can we think about the landscape vertically by observing it in situ and with a map in hand to annotate its distinctive features and outline its structuring forms?

The strategy involved drawing the principal overlapping visual planes of the landscape, using techniques and knowledge associated with map-making.

The body was engaged in on-site drawing, emphasising the haptic dimension. The field of view, the distance to the picture plane, the framing, and the observed silhouettes abstracted from the landscape support and circumscribe it and highlight the observer's position.

Some cartography drawing methods formed the core resources provided in the workshop: triangulation, measurement, scale, notation, legend, outline and inner contours, and transparency. Additionally, three mediating devices were introduced: two optical—a "Velo" and an analogue camera lucida—and one digital—a mobile phone photography application.

The ambitious objective was to empower future teachers with drawing as a cognitive tool, enabling them to replicate this activity in their future classrooms' teaching context.

**TASK** To draw cityscapes from an elevated vantage point, using the city plan as a reference, analysing the field of view and employing measurements and optical mediating devices, such as drawing machines—simple mechanical or optical aids, and digital devices.

**AIMS**

- To explore the drawing of city views based on some fundamental cartographic knowledge and techniques.
- To consolidate the understanding of the observer's spatial position, their field of view, and the visual planes of the landscape to be outlined, both on the city map and on the vertical picture plane, where each student will draw the landscape.
- To enhance the learning outcomes by incorporating optical and digital mediator devices to support cognitive observational drawing.
- To assert Drawing as an epistemic tool—a visual and cognitive medium boosting spatial thinking and knowledge.
- To investigate the relevance and applicability of teaching/learning/assessment methods within the educational field of future Geography teachers.

**TIME FRAME** 180 minutes.

## MATERIALS AND PREPARATIONS

Acrylic sheets (3mm thickness) featuring the visual field, main visual vertical line, and observer's horizon line (marked in advance on the back of the sheet, opposite the drawing surface, to avoid being erased).

Tripods to stabilise and position the acrylic sheets.  
Camera lucida devices.  
Mobile phone applications to support observational drawing.  
Drawing paper of varying types and qualities.  
Acetate pens and other drawing materials.  
Drawing boards.  
Binder clips to secure paper to the drawing boards.  
Alcohol at 96° to clean the acrylic sheets.

---

## INSTRUCTIONS

---

### GENERAL GUIDELINES

---

Participants will work individually or in pairs, actively encouraging peer discussion.

Three observation points must be set up in advance, each equipped with a distinct optical device: 1) acrylic sheets supported or mounted on tripods, 2) camera lucida devices attached to drawing boards supported by tripods, 3) mobile phone drawing support applications.

Each student should be provided with a map of the location, indicating the visible area of the territory that they can draw from their position.

Before beginning the activity, students should learn a brief but focused introduction explaining the objectives, tasks, and working methods.

---

### SPECIFIC GUIDELINES

---

Considering the relationship between the map and the landscape, students must be aware of the importance of the observer's positioning, point of focus, field of view, main visual vertical plane, observer's horizon plane, and the impact of framing on the drawing.

On the map, the observation place and field of vision will be identified and registered, as well as the significant points of the landscape and the frontal foreground planes that allow for its subdivision.

Upon arriving at the observation positions, students will receive instructions on using each device and have some time to familiarise themselves with the equipment.

The participants will produce observational drawings from three designated points on site, mediated by optical devices, and apply the abovementioned strategies.

Throughout the drawing process, ongoing discussion will be encouraged between what is represented on the map and what is drawn in perspective.

---

### TIPS AND THINGS TO CONSIDER

To execute a landscape drawing from any of the three selected observation points on site, one must follow the steps:

- To use only one eye—the observing eye.
- To understand that the field of view is an abstraction of the surface of a cone of revolution, with its vertex at the observing eye, the principal line of sight

as its axis, and a maximum angle of 60° between any two generatrices.

- To understand that the distance between the observer and the drawing plane will determine the size of the circumference—the field of view limit on the drawing sheet.
- To maintain fixed consistency throughout the process, the drawing device and the distance between the observing eye and the drawing surface.
- To ensure that the observer's horizon line is levelled.
- Always look towards the same fixed point, selected as the target of the main line of sight; also, ensure two further fixed points along the observer's horizon line—one positioned at the far left and the other at the far right.
- To understand landscape drawing as delineating the outlines and inner contours of the foreground and overlapping visual planes, allowing the visual reading of the forms within the landscape.
- To be aware that mobile phone drawing support applications produce a fixed, non-optical, and transparent image. When this image on the device is aligned parallel to the drawing surface and positioned between the observing eye and the drawing hand, it can effectively guide the drawing process.
- To understand that the camera lucida optical device offers a fragmented visual perception of reality, demanding heightened attention when drawing the image onto paper.

## REVIEW

Understanding a territory—its description, the recognition of its boundaries, and the comprehension of the phenomena, dynamics, and relationships observable within it—and the positioning of the human body in space are long-standing areas of exploration within Geography. Drawing, through epistemological proximity, soon became allied to these practices, clarifying and recording knowledge through cartographic representation. Maps emerged as one of the most effective graphic productions for synthesising spatial organisation.

However, further practices have been shared across these two fields. Among them are field visits and walking performances, often formalised in field notebooks. These notebooks offer both speed and selectivity, enabling the registration of essential data. Jorge Gaspar (2021, p. 52) acknowledged the value of drawings as models and the act of drawing as a method for modelling emphatic syntheses of observed phenomena. The remarkable field notebooks of Portuguese geographer Orlando Ribeiro are exemplary cases. For Ribeiro, fieldwork and direct observation formed the foundation of geographic research. His notebooks combined map and landscape drawings, complemented by notations, annotations, and analytical tools such as cross-sections, transparencies, and overlays. These methods enabled him to construct provisional syntheses that bridged realistic representation and theoretical schemata. In his advocacy for learning through drawing, Ribeiro emphasised the heuristic value of drawing, unconcerned with aesthetic or mimetic dimensions (1941, 1943).

This workshop builds conceptually on that historic partnership, seeking new insights to help answer one of the research questions of the DRAWinU project: What learning processes can be stimulated through drawing activities to enhance understanding of visual, spatial, and temporal content in STEM areas?

Therefore, the workshop was designed for students enrolled in the Master in Teaching Geography in the 3<sup>rd</sup> Cycle of Basic Education and Secondary Education—at the Faculty of Arts and Humanities of the University of Porto. Its general aim was to test practices of drawing-based map construction to develop geographical knowledge of the landscape. Moreover, given the participants' prospective roles as teachers, the activity was also intended to showcase its pedagogical relevance. It aimed to demonstrate how Drawing-based activities in STEM subjects can significantly enhance Geography's teaching, learning, and assessment processes.

A few key considerations informed the adopted method. Specifically, it drew a parallel between the critical role of maps in understanding territorial organisation and the views on haptically comprehending landscapes. If the cartographer gazes at the overall of a territory, the perspectivist drawer observes the partial. In cartography, the observer's position is rational and abstract, or detached. In contrast, in perspective drawing, the embodied presence of the observer determines the visual field, which is perceptive and framed. Accordingly, considering gravity's influence, the horizontal arrangement of phenomena and dynamics tends to preclude overlaps and inner contours in cartographic representations. Conversely, outlines and overlaps are abundant in landscape depictions, viewed from eye level and drawn on a vertical plane. Therefore, it suggests sequential frontal planes that can be analytical subdivisions of landscape components.

The operational aim of the workshop was to question the capacity and suitability of cartographic products such as *Landscape Character Assessment* (LCA) Maps to capture the complexity of territorial experience. With that purpose, the method emphasised the haptic dimension of drawing and its role in understanding the landscape. Aligned with Geography's strong tradition of active observation, the workshop underscored the integration of cartographic representation and field notebooks. The method pursued the goal of guiding the geographer's eye toward the landscape without losing sight of the map.

The workshop offers three drawing exercises differentiated by the mediating drawing device used.

The first drawing exercise employed a transparent acrylic sheet, interpreting the conceptual Alberti's "veil" (1435). Participants drew the main contours of the landscape directly onto the acrylic. It was unnecessary to think of drawing instruments with the precision of Dürer or closed-grid systems described by Alberti as a *thin veil*. The essential idea was to show that a geometric system underlies vision.

Participants began by locating their position on the city's tourist map and within the selected space. From there, as in cartography—albeit for different reasons—a set of parameters necessary for the observational drawing was taught. These are derived from linear perspective and are present in today's image-making tools, such as cameras and digital apps, which form the basis of the two subsequent exercises. Thus, the drawing process was understood not as a faithful reproduction of reality but as a simulation and selection captured during a specific observation in a single moment. In this sense, drawing became a process of learning about the landscape.

Starting the exercise, participants established a fixed, horizontal line of sight towards a prominent point in the landscape—the primary target. Students carried out this task both on the map and in the drawing. It would correspond to the centre of the camera's viewfinder in photographic terms. After that, the concept of a visual field—a compromise between what a stationary eye sees and what it can depict—was introduced. Human binocular vision spans approximately 120° horizontally and 130° vertically. To support this understanding,

we used the abstract idea of a conical visual field, described as the surface of a cone with its vertex at the observer's eye, aligned with the main line of sight, and having a 30° angle between the axis and generatrix. Its orthogonal projection onto the map and its simulation through outstretched, level arms defined the framing circle, formed by the intersection of the cone surface and the acrylic sheet.

The observer's distance to the acrylic was marked on the map, ensuring the largest possible framing circle within the reach of the drawing hand. The visual cone surface abstraction also involved two perpendicular planes along the main line of sight—one of which was the observer's horizon plane. The intersection of these planes with the acrylic, along with the framing circle, created a viewfinder and established the actual spatial position of the observer to the subject of the drawing. In cartographic drawing, the observer's position—here, an abstract figure located at infinity—is also fundamental to define a primary attribute of cartographic products: scale and measurement. Under these conditions, participants could focus on identifying and representing the main formal structures of the landscape through triangulation, outlining, and annotation. The new drawers used a triangulation strategy to mark key points on the outer and inner contours of the principal foreground planes, subdividing the landscape. These planes were imagined on the map, while their outlines were depicted in the drawing.

Both the viewfinder and map allowed participants to return to their drawing at any time by re-aligning the key point of the landscape with the centre of the viewfinder and matching the two reference points previously taken from the landscape with the left and right intersections of the observer's horizon line with the framing circumference.

The second exercise employed drawing support software on mobile devices, exploring the convergences between drawn and photographic representations. The first exercise's parameters, conditions, and precautions were the same. A focal length of 50mm is a reasonable approximation in photography to the human eye's vision, balancing visual amplitude and optical distortion (Bartrina, 2001). However, unlike human physiology, cameras allow variation in this amplitude depending on lens focal length and sensor size. The primary difference between camera lenses and the human visual system lies not in the angle of vision but in the focal area—formed on a flat surface (sensor or paper), unlike the curved retina.

Functional similarities between the acrylic viewfinder and the cameras allowed the learning from the first exercise to be applied here.

The view was captured using a smartphone camera and displayed as a transparent overlay on the screen. Positioned horizontally and parallel to the drawing sheet, the phone enabled the participant to trace the landscape's outer and inner contours, guided by the semi-transparent image. Maintaining visual stability, a steady device, and fine motor control required adherence to the highlighted precautions. Participants came to understand that this was not drawing from direct observation.

The third drawing exercise involved the use of a camera lucida. It maintained the parameters, strategies, and precautions from the earlier exercises. As with the mobile software, the screen's dimensions dictated the visual field and viewfinder dimensions. With the camera lucida, the small optical prism necessitates the observer's eye to be in very close proximity, thereby determining the size of the drawing (Stanley, 1868, pp. 115-117). However, the key difference between this device and photographic software lies in the image's origin: digital images are processed electronically, while those produced by the camera lucida result from physical optical operation. Unlike the fixed images of free mobile apps, the camera lucida offers a real-time experience. These limiting and stimulating constraints

raised participants' awareness of their drawing experience as unfolding in time. The camera lucida stressed the importance of drawing as a conductor of an experience in time, and not only as a tool to obtain a visual result.

Despite the visual similarities among the resulting drawings of the three exercises, the images produced through seeing, photographing, and drawing are fundamentally different. The mediating devices engaged questions of human physiology, perception, optics, and the nature of the tools. Therefore, they helped participants better understand and control the drawing of the city's views, depicting them more legibly.

Thinking about the landscape as projected onto a vertical plane can pose a challenge for educational contexts of Geography. However, mastering this conceptualisation can contribute to a deeper geographical understanding of landscape.

The workshop centred on an observational drawing-based activity, proposing a methodology for outlining landscape features using key cartographic drawing techniques, mediated by optical devices. This technical appropriation enabled a bridge to be established between cartographic and landscape drawing. It also highlighted Drawing's haptic qualities: the observer's spatial immersion reinforced awareness of the landscape's potential for multiple, complementary interpretations. Simultaneous readings of territory and landscape were presented to be beneficial. Despite conceptual differences, the transferability of methods between cartographic and landscape drawing became evident. The workshop emphasised the role of active observation as fundamental to both Geography and Drawing.

An anonymous survey at the end revealed a high level of satisfaction, with participants recognising Drawing as a valuable tool in knowledge construction and its relevance in educational contexts of Geography.

## EXAMPLES



FIG. 1 Putting Maps into Perspective: Drawing Territory and Landscape in Geography (explaining the activity on the map). Terreiro da Sé, Porto. 6th November 2023.



FIG. 2 Putting Maps into Perspective: Drawing Territory and Landscape in Geography (drawing on the acrylic sheet). Terreiro da Sé, Porto. 6th November 2023.



FIG. 3 Putting Maps into Perspective: Drawing Territory and Landscape in Geography (Drawing with the mobile phone app). Terreiro da Sé, Porto. 6th November 2023.



FIG. 4 Putting Maps into Perspective: Drawing Territory and Landscape in Geography (drawing with the map and the camera lucida). Terreiro da Sé, Porto. 6th November 2023.



FIG. 5 Planning and drawing on the map, 2023. Pencil on a tourist map of Porto (40,2 x 80,2 cm).



FIG. 6 Drawing of the main line of sight, the visual field, and the frontal foreground planes that allow for the landscape subdivision, 2023. In the top left corner of the map, the field of view is drawn as an abstraction of the surface of a cone of revolution. Gel ink pen on a tourist map of Porto (40,2 x 80,2 cm).



FIG. 7 Student drawing on the acrylic sheet with a triangulation strategy to mark key points on the outer and inner contours of the principal foreground planes, subdividing the landscape, 2023. Acetate pen on acrylic sheet, featuring the visual field, main visual vertical line, and the observer's horizon line, marked in advance on the back of the sheet, opposite the drawing surface, to avoid being erased (50x30 cm).

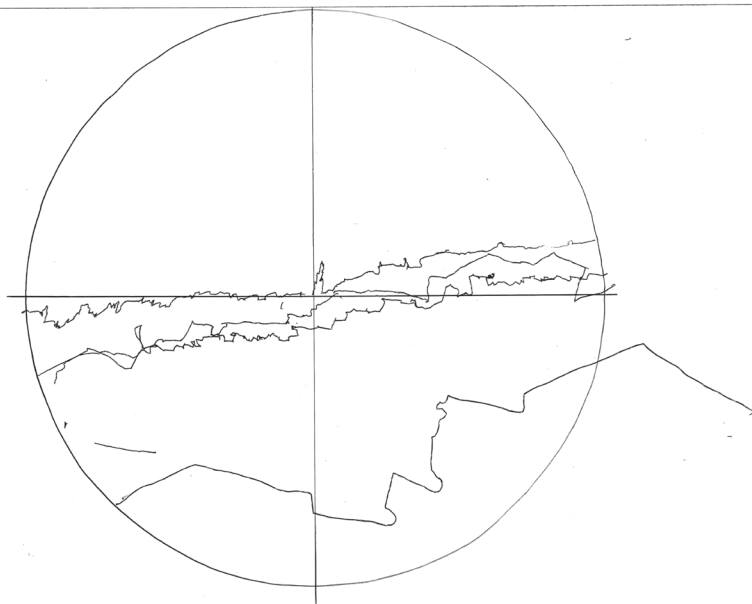
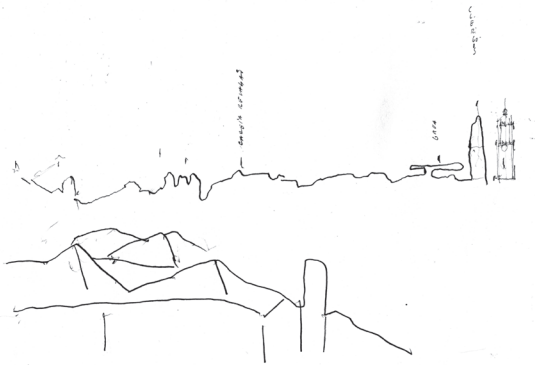


FIG. 8 Drawing on the acrylic sheet of the outer and inner contours of the principal foreground planes, 2023. Digitisation of the drawing executed on the acrylic sheet (50x30 cm).



João Fernandes  
 Juliana Alves

FIG. 9 Outlines of the principal foreground planes, drawn with the support of a mobile phone application for observational drawing, 2023.  
 Pen on A3 paper (42x29,7 cm).



Pub  
 Bernardo Nunes  
 Feito com a app

FIG. 10 Outlines of the principal foreground planes, drawn with the support of a mobile phone application for observational drawing, 2023.  
 Pencil on A3 paper (42x29,7 cm).

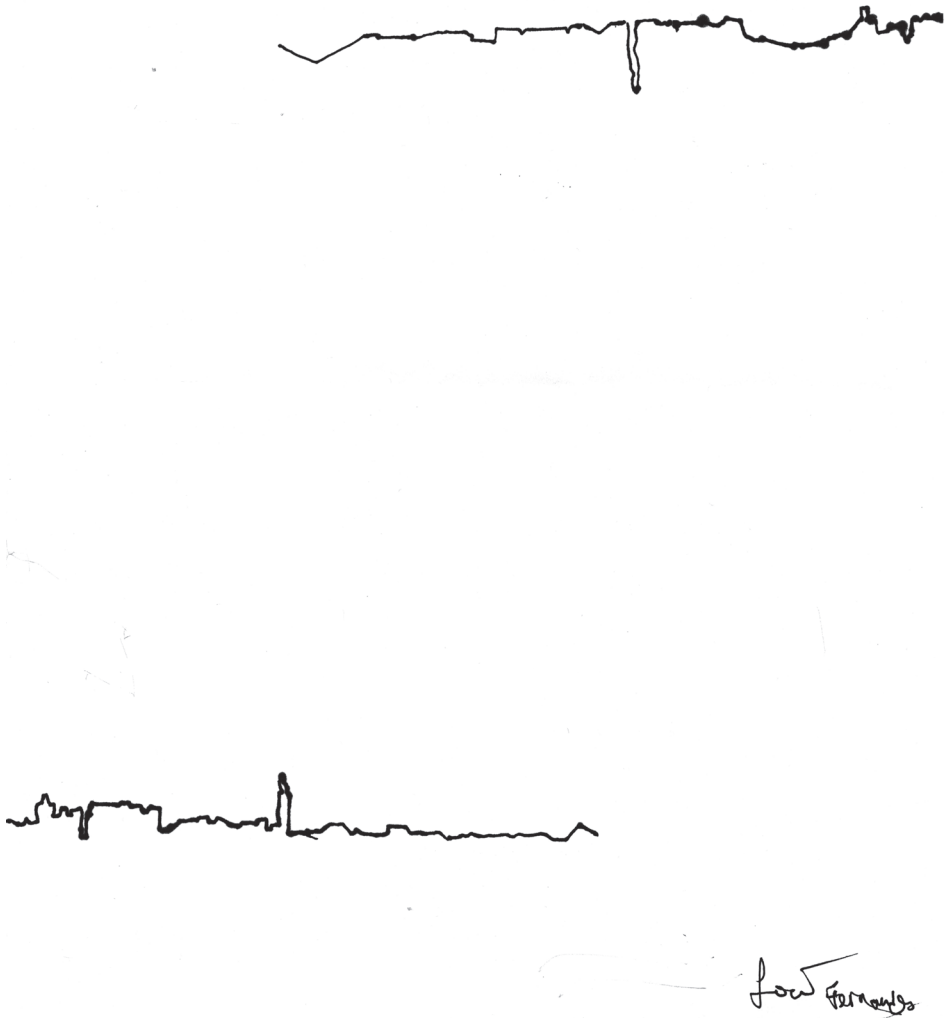


FIG. 11 Outlines of the principal foreground planes, drawn with the support of a camera lucida, 2023. Gel ink pen on A4 paper (21x29,7 cm).



FIG. 12 Outlines of the principal foreground planes, drawn with the support of a camera lucida, 2023. Gel ink pen on A4 paper (29,7x21 cm).



# Acknowledgements

Between 2022 and 2025, the DRAWinU project developed fifteen collaborative workshops with the School of Medicine and Biomedical Sciences Abel Salazar, the Faculty of Medicine, the Faculty of Engineering, the Department of Geography of the Faculty of Arts and Humanities, the Department of Physics and Astronomy and the Center for Research in Mathematics in the Faculty of Sciences, and the Institute of Research and Innovation in Health Sciences of the University of Porto.

The workshops were designed as a proof of concept, translating the research findings on drawing activities in STEM environments at the University of Porto into specific learning contexts to develop goal-oriented strategies in response to STEM content, through collaboration and co-creation with other professors and students. More than reinforcing hypercodified forms and procedures of visual representation in science, we embraced the challenge of entering new learning places by accepting the inevitability of not knowing and the will to participate in the search for new solutions to old problems. Like in any other form of research, knowledge through drawing is generated through exploratory experiments, hypothesis testing, and through a process open to contingencies.

At the end, similar drawing strategies resonated across workshops. This similarity is extremely relevant as a common ground for changing the attitude towards drawing and its value, especially in those cases where it is perceived as an alien approach to learning and research, and whose impact is relatively independent of the content being addressed. In most cases, the workshops required effort to address specific problems, but also to raise new questions that we could not even think about without the interactive environment provided by the drawing workshops.

This work would not have been possible without the contributions of all the students who were challenged to co-create the workshops with us, and who also challenged us to review our own beliefs about what drawing is in a STEM context and what we can do with it. Our appreciation goes to the professors of the hosting Institutions for their support, engagement, and for providing us with food for thought. We are especially grateful to

Maria Strecht Almeida for opening the School of Medicine and Biomedical Sciences Abel Salazar—ICBAS to our experiments and for giving her advice whenever it was needed. This gratitude is extended to Isabel Cardoso and Ana Magalhães, also from ICBAS, for their insights and participation in the drawing experiments around metabolic maps; to Orfeu Bertolami and João Horta Belo from the Faculty of Sciences, and José Ramalheira Vaz from the Faculty of Fine Arts for bridging the concept of entropy and drawing from the perspective of physics and art.

We want to acknowledge the fascinating drawing experiment leading to the workshop on visualising interoception by the artist Garry Barker from Leeds Arts University.

This work was part of the DRAWinU Project, funded by the Foundation for Science and Technology (PT), reference PTDC/ART-OUT/3560/2021. We are immensely grateful for this support, enabling us to share the book in open access. This also underscores our responsibility to counteract the short life cycles of project frames by finding new ways to continue the work synthesised here.

We are delighted to see the book finally published, made possible by the collective dedication of everyone involved.

# References and further reading

## LEARNING BY HAND

Ainsworth, Shaaron; Prain, Vaughan; Tytler, Russell (2011). Drawing to Learn in Science. *Science*, Vol. 333, August 2011, 1096-1097.

Ainsworth, Sharon E.; Scheiter, Katharina (2021). Learning by Drawing Visual Representations: Potential, Purposes, and Practical Implications. *Current Directions in Psychological Science*, Vol. 30 (1), 61-67.

Anderson, Gemma (2017). Drawing as a Way of Knowing in Art and Science. Intellect Books, UK.

Anderson, Gemma (2021). Forking Paths: depicting mitosis through process-based diagramming. *Journal of Visual Art Practice*, 20:3, 275-281.

Anderson, Gemma; Dupré, John; Wakefield, James G. (2019). Drawing and the dynamic nature of living systems. *eLife* 2019; 8:e46962.

Fiorella, Logan (2023). Making Sense of Generative Learning. *Educational Psychology Review* (2023) 35:50.

Fiorella, Logan, & Mayer, Richard E. (2015). Learning by Drawing. In *Learning as a Generative Activity: Eight Learning Strategies that Promote Understanding*, 62-78. Cambridge University Press.

Hoffmann, Christoph; Wittmann, Barbara (2013). Introduction: Knowledge in the Making: Drawing and Writing as Research Techniques. *Science in Context* 26(2), 203-213. Cambridge University Press.

<https://doi.org/10.5195/ijms.2014.186>

Quillin, Kim; Thomas, Stephen (2015). "Drawing-to-Learn: A Framework for Using Drawings to Promote Model-Based Reasoning in Biology". *CBE-Life Sciences Education*. Vol. 14(1), 1-16.

Simmons III, Seymour (2021). *The Value of Drawing Instruction in the Visual Arts and Across Curricula*. Routledge

Tversky, Barbara (2011). Visualizing Thought. *Topics in Cognitive Science*. 3(3), 499-535.

Van Meter, Peggy; Garner, Joanna (2005). "The promise and practice of learner-generated drawing: literature review and synthesis". *Educational Psychology Review*. Vol. 17 (4), 285-325.

Wu, Sally P. W.; Rau, Martina A. (2019). How Students Learn Content in Science, Technology, Engineering, and Mathematics (STEM) Through Drawing Activities. *Educational Psychology Review*.

## WARM-UP GAMES

Edwards, Betty (1999). *Drawing With the Right Side of the Brain*. Jeremy P. Tarcher/ Putnam.

Maslen, Mick; Southern, Jack (2011). *Drawing Projects—An Exploration of the Language of Drawing*, Black Dog Publishing.

Nicolaides, Kimon (1941). *The Natural Way to Draw—A Working Plan for Art Study*. Houghton Mifflin Company.

Wakefield, James G. (2023). *Flow, Attend, Flex: Introducing a Process-Oriented Approach to Live Cell Biological Research*.

in *Drawing Processes of Live*  
—*Molecules, Cells, Organisms*.  
Edited by Gemma Anderson-Tempini  
and John Dupré. Intellect

WORKSHOP 1:  
POLARISING ATTENTION:  
DRAWING UNDER THE MICROSCOPE

Bredenkamp, Horst; Dünkel, Vera;  
Schneider, Birgit (2015). The Image—  
A cultural technology: A research  
program for a critical analysis of images.  
In *The Technical Image*. The University  
of Chicago Press, 1-5.

Damásio, António (2018). *A Estranha  
Ordem das Coisas*. Círculo de Leitores.

De Rijcke, Sarah (2008). Drawing  
into abstraction. Practices of observation  
and visualisation in the work of Santiago  
Ramón y Cajal. *Interdisciplinary Science  
Reviews*, Vol. 33(4), 287-311

Doherty, Meghan C. (2012). Discovering  
the ‘True Form’: Hooke’s Micrographia  
and the visual vocabulary of engraved  
portraits. *Notes & Records of the Royal  
Society*. 66(3), 211-234.

Dünkel, Vera (2015). Comparing Images.  
In Bredenkamp, H.; Dünkel, V.; Schneider,  
B. (2015). *The Technical Image*. The  
University of Chicago Press, 14-17.

Jabr, Ferris (2013). Why the Brain Prefers  
Paper. *Scientific American*. 309(5), 48-53.

Jack, Jordynn (2009). A pedagogy  
of Sight; Microscopic Vision in Robert  
Hooke’s Micrographia. *Quarterly  
Journal of Speech*. 95(2), 192-209

Lyon, Philippa M.; Turland, Martha  
(2020). Visualising the body: health

professionals’ perceptions of their clinical  
drawing practices. *Medical Humanities*.  
46(4), 1-10.

Lyons, Lucy (2012). Drawing your way  
into understanding. *Tracey—Drawing  
and Visualization Research: Drawing  
Knowledge*. Loughborough University

Pacherie, Elisabeth (1995). Do we see with  
microscopes?. *The Monist*. 78 (2), 171-188.

OCR (2015). *A Level Biology Drawing Skills—  
Biological Drawing*. Cambridge University  
Press & Assessment.

Quillin, Kim; Thomas, Stephen (2015).  
Drawing-to-Learn: A Framework for  
Using Drawings to Promote Model-Based  
Reasoning in Biology. *CBE-Life Sciences  
Education*. Vol. 14(1), 1-16.

Salazar, Abel (1932). Procédé Rapide de  
Dessin Microscopique. *Separata Folia  
Anatomica Universitatis Conimbricensis*.  
Vol. VII (12).

Salazar, Abel (1943). Desenho Histológico.  
In Costa, A Celestino da; Chaves, P. Roberto.  
*Manual de Técnica Histológica—Guia de  
Trabalhos Práticos*. 3ª edição. Livraria  
Portugália, 49-67.

Van Meter, Peggy; Garner, Joanna (2005).  
The promise and practice of learner-  
generated drawing: literature review and  
synthesis. *Educational Psychology Review*.  
Vol. 17 (4), 285-325.

WORKSHOP 2:  
TACTILE DRAWING:  
MANIPULATION AS A PROCESS OF ANALYSIS  
AND REPRESENTATION IN OSTEOLOGY

Mau, B. (1998). Incomplete Manifesto  
for Growth. Available at: <https://www.>

brucemaudesign.com/incomplete-manifesto [Accessed 4 Feb. 2025].

Naghshineh, S., Hafler, J. P., Miller, A. R., Blanco, M. A., Lipsitz, S. R., Dubroff, R. P., Khoshbin, S., & Katz, J. T. (2008). Formal art observation training improves medical students' visual diagnostic skills. *J Gen Intern Med*, 23(7), 991-997. <https://doi.org/10.1007/s11606-008-0667-0>

Reid, S., Shapiro, L., & Louw, G. (2019). How Haptics and Drawing Enhance the Learning of Anatomy. *Anat Sci Educ*, 12(2), 164-172. <https://doi.org/10.1002/ase.1807>

Shapiro, L., Bell, K., Dhas, K., Branson, T., Louw, G., & Keenan, I. D. (2020). Focused Multisensory Anatomy Observation and Drawing for Enhancing Social Learning and Three-Dimensional Spatial Understanding. *Anat Sci Educ*, 13(4), 488-503. <https://doi.org/10.1002/ase.1929>

Toro-Huamanchumo, C. J. and Arce-Villalobos, L. R. (2014). The Clinical Eye: A Need to Improve the Teaching of Semiology in Undergraduate Medical Education. *International Journal of Medical Students*, 2(3), 144.

Wammes, J., Meade, M., & Fernandes, M. (2015). The Drawing Effect: Evidence for Reliable and Robust Memory Benefits in Free Recall. *Quarterly journal of experimental psychology*, 69(9), 1-62. <https://doi.org/10.1080/17470218.2015.1094494>

WORKSHOP 3:  
DRAWING METABOLIC MAPS  
– SIMPLIFYING COMPLEXITY

Bock von Wülflingen, B. (2019). Diagrammatic Traditions: Color in Metabolic Maps. In *Science in Color:*

*Visualizing Achromatic Knowledge* (207-218). Walter de Gruyter GmbH. <https://doi.org/10.1515/9783110605211-013>

Pokojná, H., Isenberg, T., Bruckner, S., Kozlíková, B. & Garrison, L. (2025). The Language of Infographics: Toward Understanding Conceptual Metaphor Use in Scientific Storytelling. *IEEE Transactions on Visualization and Computer Graphics*, 31(1), 371-381. <https://doi.org/10.1109/TVCG.2024.3456327>.

Ferreira, P. M. (2025). Personal communication, April 25, 2025

WORKSHOP 4:  
THE VISUALISATION OF INTEROCEPTION:  
DRAWING THE FEELINGS AND SENSATIONS  
THAT WE HAVE INSIDE US

Ceunen, E., Vlaeyen, J.W. & Van Diest, I. (2016). On the origin of interoception. *Frontiers in Psychology*, 7, 743.

Cytowic, R.E. (2002). *Synesthesia: A union of the senses*. MIT press.

Iosifyan, M. & Korolkova, O. (2019) *Emotions associated with different textures during touch* *Journal of Consciousness and Cognition*. 71(1), 79-85,

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. University of Chicago Press.

Sahib S. Khalsa, et al. (2018). *Interoception and Mental Health: A Roadmap*, *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*. 3(6), 501-513, <https://doi.org/10.1016/j.bpsc.2017.12.004>.

Shusterman, R (2012). *Thinking Through the Body: Essays in Somaesthetics*. Cambridge

WORKSHOP 5:  
DRAWINGS AND REPRESENTATIONS  
FOR ENTROPY

Massironi, Manfredo (1982). *Ver pelo desenho*. Martins Fontes Editora

Lima, Manuel (2013). *Visual Complexity: Mapping Patterns of Information*. Architectural Press.

Lemons, Don S. (2017) *Drawing Physics: 2,600 Years of Discovery From Thales to Higgs*. MIT Press.

Tufte, Edward R. (1997). *Visual Explanations: Images and Quantities, Evidence and Narrative*. Graphics Press.

WORKSHOP 6:  
DRAWING BEYOND THE PLANE:  
EXPLORING RIGHT-ANGLED  
TRIANGLES IN SPHERICAL GEOMETRY

Fischbein, E. (1993). The theory of figural concepts. *Educational Studies in Mathematics*, 24(2), 139-162. doi:10.1007/BF01273689

Mena-Matos, H. & Cardoso, V. (2023). Drawing to visualise in mathematics. In Bismarck, M. et al. (ed.) *Drawing across Borders: Learning, Research and Communication through Drawing in the University*. Porto: i2ADS/FBAUP. pp. 289-320. ISBN: 978-989-9049-38-3

Simões, S., & Alegria, P. (2023). Drawing in the University Today: A Tool to Think in Engineering. In B. G. Rangel (Ed.). *Integrated Project Design. Digital Innovations in Architecture, Engineering and Construction*. Springer, 53-83.

Wu, S. P. W., & Rau, M. A. (2019). "How students learn content in

science, technology, engineering, and mathematics (STEM) through drawing activities". *Educational Psychology Review*, 31(1), 87-120. <https://doi.org/10.1007/s10648-019-09467-3>

Wynne, J., & Wilkinson, A. (2021). *Do Not Erase: Mathematicians and Their Chalkboards*. Princeton University Press. <https://doi.org/10.2307/j.ctv1bxh647>

WORKSHOP 7:  
MAPPING TERRITORIES:  
DRAWING AND REPRESENTATION OF SPACE

Bismarck, M. (2001). Os Desenhos do Desenho. In *Novas Perspectivas sobre Ensino Artístico*. Editado por Natércia Pacheco, Manuela Terrasêca, Elvira Leite. Faculdade de Psicologia e Ciências da Educação, Universidade do Porto.

Boeck, A. & Tepe, P. (2021, 25 February). What is Artistic Research?. *w/k—Between Science & Art*. "<https://doi.org/10.55597/e6798>

Bolt, B. (2007). The magic is in handling. In E. Barret and B. Bolt (Eds.). *Practice as research. Approaches to creative arts enquiry*. I.B.Tauris, 27-35.

Bourdieu, P. (1990). *The Logic of Practice*. Stanford University Press.

Cain, P. (2010). *Drawing: The Enactive Evolution of the Practitioner*. Intellect.

Fergusson, E. (2001). *Engineering and the Mind's Eye*. Massachusetts: MIT Press.

Goldfried, M. R. (2013). What should we expect from psychotherapy? *Clinical Psychology Review*, 33(5), 862-869.

Harley, J.B. & D. Woodward, D. (Eds.) (1987). *Cartography in Prehistoric, Ancient and Medieval Europe and the Mediterranean*. Vol. 1. University of Chicago Press.

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Prentice-Hall.

Kovats, T. (14, April 2021). Meet the Artist: Tania Kovats—Why I Draw [Interview made by Artspace Editors]. ARTSPACE. Available at: [https://www.artspace.com/magazine/interviews\\_features/meet\\_the\\_artist/tania-kovats-why-i-draw-56738](https://www.artspace.com/magazine/interviews_features/meet_the_artist/tania-kovats-why-i-draw-56738)

Michaud, P. (Ed.). (2005). *Comme le rêve le dessin*. Louvre et Centre Pompidou.

Petherbridge, D. (2008). Nailing the Liminal: The Difficulties of Defining Drawing. In S. Garner (Ed.). *Writing on Drawing. Essays on Drawing Practice and Research*. Intellect, 27-57.

Petherbridge, D. (2010). *The Primacy of Drawing: Histories & Theories of Practice*. Yale University Press.

plásticas. *PSIAX, Estudos e reflexões sobre Desenho e Imagem*. 3, 87-94.

Rheinberger, H. J. (1992). Experimental Systems: Difference, Graphematicity, Conjunction. In *Experiment-Difference-Writing. On the History of Epistemic Things*. Basiliken-Press.

Simões, S.; Almeida, P. L. & Marques, J. (2018). Desenhar na incerteza: da invisibilidade do processo à visibilidade do projeto nas artes

WORKSHOP 8:  
PUTTING MAPS INTO PERSPECTIVE:  
DRAWING THE TERRITORY AND LANDSCAPE IN  
GEOGRAPHY

Daveau, Suzanne (Coord) (s.d). Cadernos de Campo. Orlando Ribeiro. <https://orlandoribeiro.igot.ulisboa.pt/cadernos/index.htm>

Alberti, L.B. (2011). *On Painting* (1<sup>st</sup> Ed. 1435). Yale University Press.

Bartrina, L. V. (2001). *Perspectiva Lineal. Su Construcción y su relación con la fotografía*. Edicions Upc.

Dürer, A. (2018). *Underweysung der Messung: Mit dem Zirkel Uñ Richt Schent, in Linien Ebnen Unnd Gantzen Corporen* (Classic Reprint, 1525). Forgotten Books.

Gaspar, J. (2021). “Desenhar com o Território”. In Cardoso, V., Fernandes, M. G. e Rodrigues, C. (Eds.) *Representações, Desenhos e Imagens do Território*. Edições i2ADS, CEGOT e CITTA.

Ribeiro, O. (1941-1943). “Orientações modernas da Geografia—Excurso 1.º—O desenho e a geografia”. In Ribeiro, O. (2011) *O Ensino da Geografia*. Porto Editora, 108-109.

Stanley, W. F. (1868). *A Descriptive Treatise on Mathematical Drawing Instruments. Their Construction, Uses, Qualities, Selection, Preservation, and Suggestions for Improvements, with Hints Upon Drawing and Colouring*. Published by the Author, at: 5, Great Turnstile, Holborn, London, W.C.



Sketching STEM:  
A Hands-On Guide on  
Drawing-to-Learn Approaches

EDITORS	Paulo Luís Almeida Mário Bismarck	i2ADS—Institute of Research in Art, Design and Society Faculty of Fine Arts, University of Porto
AUTHORS	Ana Magalhães Cláudia Amandi David Lopes Flávia Costa Garry Barker Helena Mena Matos Isabel Cardoso João Horta Belo Jorge Marques José Ramalheira Vaz Luís Espinheira Maria Catarina Silva Maria Strecht Almeida Marina Vale Guedes Mário Bismarck Orfeu Bertolami Paulo Luís Almeida Pedro Alegria Sílvia Simões Vasco Cardoso	i2ads.up.pt 2025 DESIGN Marta Cabral ISBN 978-989-9279-12-4 LEGAL DEPOSIT 562778/26 DOI <a href="https://doi.org/10.34626/i2ADS/2025-0010">https://doi.org/10.34626/i2ADS/2025-0010</a> PRINTING Diário do Minho PRINT RUN 200
TRANSLATION	"Warm-up games" & "Drawings and Representations for Entropy" translated from Portuguese by Paulo Luís Almeida	This work is financed by national funds through the Portuguese funding agency, FCT—Fundação para a Ciência e a Tecnologia, within the project UIDP/04395/2020 under Drawing Across University Borders (PTDC/ART-OUT/3560/2021).



