

Innovations in Science Education and Technology

Volume 26

Series editor

Karen C. Cohen

Weston, MA, USA

As technology rapidly matures and impacts on our ability to understand science as well as on the process of science education, this series focuses on in-depth treatment of topics related to our common goal: global improvement in science education. Each research-based book is written by and for researchers, faculty, teachers, students, and educational technologists. Diverse in content and scope, they reflect the increasingly interdisciplinary and multidisciplinary approaches required to effect change and improvement in teaching, policy, and practice and provide an understanding of the use and role of the technologies in bringing benefit globally to all. Book proposals for this series may be submitted to the Publishing Editor: Claudia Acuna E-mail: Claudia.Acuna@springer.com

More information about this series at <https://link.springer.com/bookseries/6150>

Jesper Haglund • Fredrik Jeppsson
Konrad J. Schönborn
Editors

Thermal Cameras in Science Education

 Springer

Editors

Jesper Haglund 
Karlstad University
Karlstad, Sweden

Fredrik Jeppsson 
Linköping University
Norrköping, Sweden

Konrad J. Schönborn 
Linköping University
Norrköping, Sweden

ISSN 1873-1058 ISSN 2213-2236 (electronic)
Innovations in Science Education and Technology
ISBN 978-3-030-85287-0 ISBN 978-3-030-85288-7 (eBook)
<https://doi.org/10.1007/978-3-030-85288-7>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer International Publishing AG 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

There is a long history of using sensors to promote inquiry in science education, pioneered notably by Dr. Robert F. Tinker more than three decades ago. In most cases, a few sensors are used to measure certain physical or chemical properties. These sensors are then connected to a computer that logs their measurements. Students typically use a line graph to plot the incoming data as a function of time to visualize the scientific effect under investigation. Through observing how a property changes graphically in response to a stimulus in the real world, students develop a concrete idea about the causal relationship between the variables in question.

Since students can arbitrarily position a sensor in an experiment, educators often need to explicitly prescribe where and when students should put it in order to capture the data as intended. While this type of cookbook-like instruction ensures that students do not miss the chance to observe the due phenomenon, it may deprive them of the opportunities to make their own scientific discoveries and the excitement experienced in such intellectual processes.

Thermal imaging provides a novel technology to support authentic science inquiry without taking away the joy of discovery. A thermal camera automatically gathers a large array of radiometric data for immediately rendering an intuitive, salient heat map visualization of a phenomenon. Such a real-time, full-field visualization of an experiment enables students to discover important details of the emergent phenomena that would otherwise go unnoticed (e.g., the thermal energy released as a result of water molecules making hydrogen bonds with cellulose molecules when a water drop falls onto a piece of dry paper). Data collection is also made as convenient as taking a picture or recording a video just like using a conventional digital camera, freeing students from tedious procedures of scanning an area with a pointwise sensor and focusing them on the fun part of doing science. Such transformative potential would not have been possible without the power of many: Compared with a single thermometer that outputs only a data point at a time, a thermal camera bundles thousands of microbolometers in a small optoelectronic device to produce a large quantity of data at once.

As this book demonstrates, science educators have been tapping into the learning and teaching potential of thermal imaging not long after it was invented. With the

plummet of price and the integration with smartphones in recent years, thermal cameras have never been more accessible to students and teachers. However, for the technology to take root and its application to grow in science education, we will need further research and development to convince schools to seriously invest in it. To this end, there may be three directions that are worth considering.

First, it is important to keep informing teachers that thermal imaging can be used to visualize any physical, chemical, and biological processes that absorb or release heat. In other words, *anything that leaves a trace of heat leaves a trace of itself under a thermal camera*. Based on this principle, we can use thermal energy as a universal indicator (passive or active) to investigate many questions in science. For example, what affects the rate of a chemical reaction can be studied using thermal imaging as a qualitative method. In the case of an endothermic reaction such as baking soda with vinegar, a petri dish filled with an aqueous reactant that is initially warm will exhibit a larger drop in temperature than another one that is initially cool when the reaction completes, suggesting that increasing temperature can speed up the reaction. Often, the challenge in broadening the application scope of thermal imaging is that it requires the participation of domain scientists to design, test, and optimize the thermal imaging equivalents of existing experimental techniques in their curricula and determine whether there are sufficient advantages to justify the conversion. This is by no means a trivial task. But if most teachers only view a thermal camera as a tool for seeing heat and are unaware of its broader applications, it would remain unlikely that schools adopt it as a main instrument for their science labs—especially in underserved districts that have a cash-strapped science budget.

Second, it is important to develop different types of apps based on the smartphone versions of thermal cameras to meet diverse needs in formal and informal science education. As a *mobile lab-on-a-chip* that can be used anywhere and connected to the cloud as part of the emerging Internet of Things, a thermal camera has tremendous potential for learning and teaching in different settings, particularly when integrated with other technologies. For example, the Infrared Street View project funded by the U.S. National Science Foundation at the Institute for Future Intelligence is a citizen science program that engages students to create thermal panoramas of their communities to survey their thermal landscapes. The project uses smartphone sensors to determine the location and orientation of a thermal image being captured by a thermal camera attached to the smartphone. Such thermal landscapes provide rich information about building energy efficiency, urban heat islands, solar energy potential, wildfire prevention, and so on that are relevant to personal issues in everyday life and global issues about climate change.

Third, it is important to develop learning and teaching theories to uncover the instructional power of thermal imaging as an example of *augmented cognition*, on a par with the active educational research on augmented reality. Many science concepts are difficult to students because they cannot be readily seen in the real world. One can only imagine how much thermal vision could help students overcome those cognitive barriers by simply empowering them with an additional sense to see a whole new world that is previously hidden from them. On the other hand, we all know that no technology can miraculously become a good educational

tool without research to unpack how people may learn and teach with it. Sound theoretical framing and solid empirical evidence based on appropriate principles and approaches from the learning sciences would help us make a more compelling case for thermal imaging to science educators and policy makers.

Without a doubt, the efforts of the small international community represented by the contributors to this book are highly commendable. With their foundational work and continuous commitment, the power of thermal imaging is bound to enlighten more students around the world in the future. It is also our hope that this book will inspire even more applications to push the envelope of this fascinating field.

Chief Scientist
Institute for Future Intelligence
February, 2021

Charles Xie

Contents

1	Introduction	1
	Jesper Haglund, Fredrik Jeppsson, and Konrad J. Schönborn	
Part I Thermal Imaging Technology and Physics		
2	Fundamentals of Thermal Imaging	7
	Michael Vollmer	
3	Thermal Infrared Imaging as a Bridge Between Mathematical Models and the Laboratory	27
	Stefano Oss	
Part II Science Education Research on the Use of Infrared Cameras		
4	Research on Educational Use of Thermal Cameras in Science: A Review	47
	Christopher Robin Samuelsson	
5	Using Thermal Cameras in Secondary Physics to Support Learning About Energy	63
	Jeffrey Nordine, Susanne Weßnigk, and Larissa Greinert	
6	Students' Emotions Related to Thermal Camera Activities in Primary Science Lessons	79
	Anni Loukomies, Taina Makkonen, Jari Lavonen, and Kalle Juuti	
7	A Language Model Based Analysis of Pupils' Practical Work with IR Cameras	95
	Niclas Åhman and Fredrik Jeppsson	
8	Upper-Secondary Students' Use of Infrared Cameras in the Study of Animals' Temperature	111
	Jesper Haglund, Sofia Folestam, and Anna Westlund	

Part III Using Infrared Cameras in Science Teaching Practice

9 Infrared Cameras as Smartphone Accessory: Qualitative Visualization or Quantitative Measurement?	129
Michael Vollmer	
10 An Infrared Camera: Multiple Ways to Use a Modern Device in Introductory Physics Courses	147
Gorazd Planinšič, Urška Nered, and Eugenia Etkina	
11 Infrared Thermal Imaging: Applications for Physics, Chemistry and Biology Education	169
Choun Pei Wong and R. Subramaniam	
12 Visualizing and Exploring Heat in a Science Center	187
Karljohan Lundin Palmerius and Konrad J. Schönborn	
13 Conclusions and Future Outlook	205
Jesper Haglund, Fredrik Jeppsson, and Konrad J. Schönborn	

List of Contributors

Niclas Åhman Department of Physics and Electrical Engineering, Linnaeus University, Växjö, Sweden

Eugenia Etkina Graduate School of Education, Rutgers, the State university of New Jersey, New Brunswick, NJ, USA

Sofia Folestam Lillerudsgymnasiet, Vålberg, Sweden

Larissa Greinert Ricarda-Huch-Schule Hannover, Hannover, Germany

Jesper Haglund Department of Engineering and Physics, Karlstad University, Karlstad, Sweden

Fredrik Jeppsson Department of Behavioural Sciences and Learning, Linköping University, Norrköping, Sweden

Kalle Juuti Department of Education, University of Helsinki, Helsinki, Finland

Jari Lavonen Department of Education, University of Helsinki, Helsinki, Finland

Anni Loukomies Viikki Teacher Training School, University of Helsinki, Helsinki, Finland

Taina Makkonen Viikki Teacher Training School, University of Helsinki, Helsinki, Finland

Urška Nered Master student at the Faculty for Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia

Jeffrey Nordine Physics Education, Leibnitz Institute for Science and Mathematics Education (IPN), Kiel, Germany

Stefano Oss Department of Physics, University of Trento, Povo, Italy

Karljohan Lundin Palmerius Department of Science and Technology, Linköping University, Norrköping, Sweden

Gorazd Planinšič Faculty for Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia

Christopher Robin Samuelsson Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Konrad J. Schönborn Department of Science and Technology, Linköping University, Norrköping, Sweden

R. Subramaniam National Institute of Education, Nanyang Technological University, Singapore, Singapore

Michael Vollmer Department of Engineering, University of Applied Sciences Brandenburg, Brandenburg an der Havel, Germany

Susanne Weßnigk QUEST-Leibniz-Forschungsschule, Leibniz University Hannover, Hannover, Germany

Anna Westlund Lillerudsgymnasiet, Vålberg, Sweden

Choun Pei Wong National Institute of Education, Nanyang Technological University, Singapore, Singapore

Charles Xie Institute for Future Intelligence, Natick, MA, USA