A lot can change in 25 years. In 1990, major political changes led the news as the fall of the Berlin Wall in 1989 resulted in the reunification of Germany and East Germany in 1990, the eventual collapse of the Soviet Union (U.S. Department of State 2014), and major changes in foreign relations. Here, in the United States, the media continued coverage of cleanup operations in Alaska to remediate environmental damage caused when the oil tanker, Exxon Valdez, ran aground in 1989 (Fig. 1)—at the time, the largest oil spill in the nation’s coastal waters (National Ocean Service 2015). News was also being made in science and technology, and one of the biggest changes involved computers. While personal computers had been available for several years, compared to today’s models, they were slow, had considerably less memory, and their ability to display graphics and multimedia was limited. Cell phones were just coming on the market, but they certainly were not smart. And the web? It did not exist. The first web page was not created until late in 1990 by Tim Berners-Lee at the European Organization for Nuclear Research (CERN) (World Wide Web Consortium 2014).

A less visible revolution was taking place in the field of weather forecasting, partly as a result of the National Weather Service (NWS)’s Modernization and Associated Restructuring (MAR) program. MAR resulted in an almost complete reorganization of the NWS forecast field offices and ushered in new technologies, such as automated surface observations and Doppler radar. These technological advances (coupled with improvements in forecaster workstations, new satellite data, and increased computer power for...
numerical weather prediction) opened up an era in which forecasting focused on the mesoscale rather than just the synoptic scale. With an initial budget of $2 billion (U.S. dollars; the final cost would be $4.5 billion), expectations were high that forecasts in general would improve and, specifically, that warnings for severe weather would be issued with longer lead times and better geographic accuracy (Friday 1994; National Research Council 2012).

As part of the restructuring, forecast offices were closed and new ones opened in locations that provided for better radar coverage. Where possible, the offices were located at or near universities in order to promote collaboration between academia and operations (Johnson and Spayd 1996). Training NWS staff on operating and maintaining the new radar systems fell to the NWS Operational Support Facility (now the Radar Operations Center). Another part of the MAR involved training and education to ensure that the forecasters (many of whom were filling newly created positions in their offices) were prepared to take advantage of the observational data they were about to be inundated with. This goal resulted in the creation of a new entity—the Cooperative Program for Operational Meteorology, Education, and Training (COMET).

**COMET’S BEGINNINGS.** Recognizing the importance of involving the academic and research communities in MAR, the NWS approached the University Corporation for Atmospheric Research (UCAR) to establish the Committee on Forecaster Training (COMFORT). COMFORT met in 1988 (chaired by Harry Orville, South Dakota School of Mines and Technology) to discuss establishing a professional development program in mesoscale meteorology and to outline the roles for UCAR and the National Center for Atmospheric Research (NCAR). Based on the committee’s recommendations and a memorandum of understanding (MOU) with the NWS, in 1989 UCAR approved the creation of a new program within the UCAR Office of Programs (now called UCAR Community Programs), and COMET was born (Spangler et al. 1994). Although funded primarily by the NWS, it was decided to house COMET within UCAR in order to ensure strong ties with both the research and university communities, which both have been strong participants in COMET programs and governance.

As laid out in the MOU, COMET had four initial objectives:

1. support the professional development of forecasters and hydrologists by providing classroom and distance learning training that leverages the expertise of research scientists and academicians;
2. assist in transferring research results to operational forecasting practice by supporting the development and testing of new forecast methods;
3. promote the collaboration of forecasters, researchers, and members of the academic community to improve operational forecasting; and
4. advance weather forecasting and nowcasting by encouraging progress in basic and applied research.

To provide the services necessary to accomplish its objectives, COMET created three internal programs: residence, distance learning, and outreach. The residence program would provide mesoscale meteorology training to select forecasters at the COMET classroom in Boulder, Colorado. Since having all 7,000+ NWS and
military forecasters travel to Boulder would be prohibitively expensive and disruptive to forecast operations, COMET also created a distance learning program (Spangler 2007). Finally, COMET’s outreach program provided monetary support for collaborative research involving a forecast office (or offices) with a university.

COMET’s first director was Bill Bonner, who was the former director of the NWS’s National Meteorological Center. Tim Spangler, previously a professor at Northern Illinois University, filled two positions as the deputy director and the head of the residence program. Dr. Spangler replaced Dr. Bonner as director in 1992 and served until 2013 when he retired, and Dr. Rich Jeffries took the helm. In 1990, Brian Heckman (a former NWS forecaster) headed the distance learning program, and Charlie Chappell, who had retired as the director of the National Oceanic and Atmospheric Administration (NOAA)’s Office of Weather Research and Modification, managed the outreach program. The remainder of COMET’s staff numbered just five individuals (Fig. 2). At its peak, COMET had nearly 50 employees, including some based at the National Centers for Environmental Prediction to facilitate numerical weather prediction training. Today it has around 30 full- and part-time staff members (Fig. 3).

Although originally the plan was for COMET to operate until MAR was complete, the need for COMET’s services has only grown for 25 years. Providing relevant products and services has required that the organization adapt to changing needs, technologies, audiences, and budgets. The rest of this paper takes a look back at some of those changes, the challenges they brought, and how COMET has prepared itself to meet the future.

EVOLUTION OF SERVICES. Residence program. One of the first tasks for the COMET residence program was to design and offer on-site train-the-trainer courses for the NWS science and operations officers (SOOs), newly created positions in the reorganized NWS forecast offices. Originally eight weeks, the COMET Mesoscale Analysis and Prediction course (COMAP) gave SOOs a graduate-level review of mesoscale meteorology to prepare them to lead mesoscale training and research in their offices (Fig. 4). One of the unique aspects of COMAP that has served as a model for many other COMET courses is that it was planned and led by experts from both the academic or research field and from operational forecasting. As a result, COMET courses have been steered by many notable scientists such as Jim Moore (Saint Louis University, deceased), Morris Weisman (NCAR), and Brad Colman (formerly one of the first SOOs, now with Microsoft). Numerous instructors from both operational and research backgrounds have in the past and currently generously provided their time and expertise. Their service and dedication is a true testament to the importance the weather, water, and climate communities place on education and training.

Another unique feature of COMAP and other COMET courses in the early days was the use of displaced real time (DRT) case studies that simulated the work environment and provided practice in applying concepts taught in the course (Spangler et al. 1994). COMET no longer produces case studies specifically formatted to simulate the forecast office environment. However, the COMET staff still develops case studies.

Fig. 2. First photo of the COMET staff. (left to right) Charlie Chappell, Tim Spangler, Dwight Owens, Susan Jesuroga, Bill Bonner, Brian Heckman, Hanne Mauriello, Jim Bryant, and Kristi Gomez. Not shown is Wendy Schreiber-Abshire who was initially on loan from the NCAR Research Applications Program.
that use data from a variety of sources (e.g., surface, radar, satellites, and numerical weather prediction models) to solve problems in either the classroom or distance learning materials. These cases enrich the educational experience, promote transfer to work situations, and many give COMET students experience with extreme or unusual events they might rarely see in their work.

At its peak, the residence program offered up to 35 weeks a year of classes, workshops, and symposia. These have included courses on hydrometeorology, boundary layer meteorology, winter weather, climate variability, and flash flood forecasting, to name a few. In addition, workshops on mesoscale and satellite topics have been held for university faculty, NWS upper management, and others. Courses have also been designed for meteorologists and hydrologists from around the world. For example, in 2011, COMET hosted a two-week, hands-on workshop for representatives of World Meteorological Organization (WMO) regional training centers to develop their own basic hydrologic sciences online course.

One of the limitations of classroom training is the number of students that can be accommodated; in the 1990s, COMET’s classroom in Boulder, Colorado, had only enough space for
18 students. Additionally, sending students to courses is costly in terms of both travel expenses and time away from office duties. From 2006 to 2007, COMET tested the practicality of virtual training in its COMAP Boundary Layer Symposium, a fire weather development course, and a workshop on multimedia development for university faculty. The results were encouraging, with 97 students attending the three events (almost twice the number that could have been accommodated in the classroom) at a significant cost savings for the participating agencies and universities. Today, COMET annually offers about 10 classroom or virtual training sessions (Fig. 5) and also has a mobile classroom with 25 workstations that can travel to other locations, whether on the UCAR campus or at other sites. Some classes, such as the Winter Weather Course (sponsored by the Meteorological Service of Canada), are held onsite but may have an asynchronous component (e.g., completing online prerequisite material). Virtual training classes may combine web-based self-study materials and discussion forums with live online sessions that can help replicate the classroom experience. Having both live and virtual learning capabilities allows COMET to tailor its courses and workshops to the needs and budgets of its clients, regardless of where their employees are in the world.

**Distance learning.** In the early 1990s, few organizations offered computer-based learning (CBL), particularly in meteorology, so the creation of the COMET distance learning program was truly groundbreaking. The original concept was that forecasters would access a library of laser discs (Fig. 6) with mesoscale meteorology courses (called modules) using a dedicated computer [professional development workstation (PDW)] specifically designed for training in the forecast office. Similar to the residence program classes, scientific content for these modules was provided by subject matter experts from government, academia, and research institutions, and many modules included case studies or simulations to reinforce the learning content. Because of their ample storage capacity, the laser discs could contain video, animations, audio, and interactive questions with feedback—features that are still hallmarks of COMET modules.

Although innovative, the technology had some serious limitations. Each forecast office had only one PDW, and with a single module containing up to 20 h of material, scheduling training time for the entire office staff was often difficult. As more university faculty began working with NWS offices (also one of the goals of MAR), educators who saw the laser disc modules (and, in some cases, borrowed the equipment) were intrigued by the potential of CBL in their own teaching. However, the technology was too expensive and not flexible enough for broader educational needs. Those difficulties began to be resolved in 1996 when COMET started producing its modules on CDs. Now forecasters could train using any computer, including ones at home, and instructors could freely use COMET CDs in their classes. In 1997, when COMET developed its free online repository of modules, MetEd ([www.meted.ucar.edu](http://www.meted.ucar.edu)), the demand skyrocketed, and the audience for COMET CBL materials broadened to where, today, almost 45% of the users come from the education community (Fig. 7).

**Outreach program.** COMET’s outreach program was created to address the objective of facilitating the transfer of research results to operational practice.
means for accomplishing this were to provide funding for applied research studies conducted jointly by universities and operational forecasting offices. Funding was available for two types of projects:

- Cooperative projects: Proposals for these projects were funded based on a competitive review process. Awards were for 1 to 3 years, with budgets of around $20,000–$40,000 yr⁻¹.
- Partners projects: Awards for these 1-yr projects were smaller (initially $5,000, increasing to a maximum of $15,000 in 2013), and funding was awarded based on an internal COMET and NWS review.

For both types of projects, the main requirements were that there be substantial forecaster collaboration (i.e., more than just providing data) and that the research topic focuses on an operational forecasting problem. University funding could be used to provide faculty salaries (cooperative projects only), travel, student support, and so on.

Up until 2013, when federal budget constraints forced its suspension, the outreach program was funded primarily by the NWS, although other agencies [e.g., Navy, Air Force, Department of Transportation, Geostationary Operational Environmental Satellite R series (GOES-R) program] also participated at various times. In 2015, the NWS and the GOES-R program began funding partners projects again, and the National Water Center started a new program to fund both partners and cooperative projects.

In total, the outreach program has provided support for over 300 projects involving more than 80 universities and 100 forecast offices. It has served as a bridge between the academic and forecasting communities, resulting in numerous long-term partnerships that continue to advance both research and operational forecasting. Forecasters have benefitted from the expertise of leading university researchers, which has enhanced their scientific backgrounds and research skills. In addition, the projects have led to changes in the implementation of alternative forecasting and warning methodologies and protocols with significant impacts to operations, resulting in demonstrably improved forecasts (Waldstreicher 2005). Academic partners have had opportunities to do research on applied forecast problems, which give them a better understanding of the challenges forecasters face with real-world data and time constraints. University students have gained experience in the forecast environment and many have gone on to atmospheric science careers in the public and private sectors or at academic institutions.

**CHANGES IN TECHNOLOGY.** State-of-the-art educational technology included overhead projectors in the classroom and laser discs or videos for distance learning 25 years ago. Thanks to changes in computer technology, software, and the Internet, education and training today look very different, and many students expect interactive and collaborative learning available anytime and anywhere. This evolution has required the COMET staff to anticipate and adapt to technological changes as well as to the evolving needs of the program’s sponsors and others who benefit from its services.

In the distance learning program, these changes have been particularly challenging. Laser disc modules were produced from 1990 to 1997, but the tools to code them changed twice in that short period, and by 1996 production was ramping up for developing CDs. However, even at that time, it was clear the Internet was going to be a more powerful tool for distributing education than either laser discs or CDs. This would require yet more changes in software, programming.

![Fig. 6. Wendy Schreiber-Abshire of COMET uses a “state-of-the-art” (for the 1990s) laser disc to view a module on Doppler radar interpretation.](image-url)
• National Weather Association Public Education Award for innovative and outstanding efforts over the past two decades to train and educate NWS meteorologists, broadcast meteorologists, emergency managers, and professionals in academia and in enhancing weather literacy and awareness of the general public.
• AGU Excellence in Geophysical Education that acknowledges a sustained commitment to excellence in geophysical education by a team, individual, or group.
• Brandon-Hall Excellence in Learning Gold Medal Award in the custom content category awarded to “Polar Lows Ungava Bay 01 December 2000” (www.meted.ucar.edu/training_module.php?id=144#.VRrht-FquO0). This award program highlights exceptional work in the field of online learning.
• National Hurricane Conference Outstanding Achievement Award for “Community Hurricane Preparedness” (www.meted.ucar.edu/training_module.php?id=566#.VRrh9OFquO0). This award is given for outstanding and innovative achievement in any hurricane-related activity that serves as a model to others.
• NewMedia Magazine INVISION Multimedia Awards, which honor top applications in new media technology (NCAR 2014). COMET was awarded the Bronze Medal for the laser disc module “Boundary Detection & Convection Initiation.”

COMET AWARDS

- Producing web modules meant that COMET also needed a way for learners to find and access them, so in 1997 the staff developed a custom, database-driven website—MetEd. That website has also undergone many updates and improvements in the last 17 years, including an online registration system built in 2007. This system not only provides the NWS and other sponsors (Table 1) with staff training data, but universities use it to record their students’ progress, and even casual users can track their own usage. Online surveys and a rating system also allow COMET staff to receive feedback on the modules.

Just when web module development had settled into a fairly routine process, smart phones and tablets came along. Because owners of Apple products could not access COMET modules programmed with Flash, in 2013 COMET decided to abandon Flash and produce modules using the jQuery JavaScript library, HTML5, and Cascading Style Sheets 3. New modules are now fully accessible to mobile learners, which make up 11% of the COMET audience. The remaining issue is the hundreds of hours of education already

Fig. 7. Percent of COMET registrants by self-reported primary affiliation.

[Graph showing percent of COMET registrants by self-reported primary affiliation]
produced in Flash. The current process is to convert older modules to a mobile-friendly product whenever a module is being updated for science content or translated to another language. To date, about 25% of COMET modules have been converted.

Over the last quarter century, there have been massive increases in computing power that have made significant differences in COMET’s capabilities. As one example, in the early days, the workstation used by COMET’s graphic artist had a Micron 386 processor with a few hundred megabytes of memory, and processing a simulation could take days. Today, his system has a 16-core processor with 64 gigabytes of memory, and processing is so fast he can run multiple simulations at the same time. This means that animations can be produced much faster, leaving time for greater creativity, detail, and complexity (Fig. 9).

Computer storage has also increased dramatically as costs have decreased, and this has improved the behind-the-scenes functions of both production and MetEd. Running out of storage was a common problem in the past. In 2000, COMET had 6 servers; now there are 30 used for various purposes. A 1-terabyte redundant array of independent disks (RAID) cost $50,000, 15 years ago. Now, for about the same price, COMET has 200 terabytes of storage. This has greatly improved the reliability of COMET systems. Multiple servers in different locations are now able to back up each other, meaning that users are able to access COMET MetEd 24 hours a day, every day.

The residence program has also benefitted from progress in computer technology. Early on, COMET

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**Table 1. Current COMET sponsors (in addition to the NWS).**

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<th>Sponsor</th>
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<td>Bureau of Meteorology of Australia</td>
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<td>Bureau of Reclamation, United States Department of the Interior</td>
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<td>European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)</td>
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<td>Meteorological Service of Canada (MSC)</td>
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<td>Naval Meteorology and Oceanography Command (NMOC)</td>
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<td>NOAA’s National Environmental Satellite, Data and Information Service (NESDIS)</td>
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<td>NOAA’s National Ocean Service</td>
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<td>U.S. Army Corps of Engineers (USACE)</td>
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experimented with using video conferencing in the classroom, but at that time the technique required special equipment on both ends. Nowadays, video conferencing over the Internet has made the COMET virtual classroom a viable alternative to sending students to residence classes. However, even the traditional COMET residence program has become more mobile. Greater computer power in smaller machines means that live classes and workshops are not tied to a single location. To keep students more engaged, COMET staff now work directly with instructors to increase interactivity throughout their presentations, and a student response system (classroom clickers) allows the instructor to view the answers to questions and immediately correct misconceptions or clarify information.

BROADENING THE AUDIENCE AND THE SCOPE. Because COMET’s beginnings are rooted in the MAR, its initial target audience was operational forecasters in the NWS, Navy, and Air Force. However, through the years as COMET’s reputation grew and needs changed, various other agencies have participated by providing financial support and guidance. Currently, COMET is sponsored by the NWS, with additional funding from the agencies listed in Table 1.

Other organizations have provided funding for specific projects. For example, the National Environmental Education Foundation sponsored several modules designed for broadcast meteorologists, and NOAA’s National Tsunami Hazard Mitigation Program funded modules about tsunamis for emergency managers, meteorologists, and children. In recent years, the variety of funding sources has resulted in many small projects on targeted subjects for a broad audience, resulting in a wider range of topics in the MetEd library (Fig. 10). Today COMET annually produces 50 h of training (compared to a production rate of 15–20 h in the early 1990s), and MetEd hosts more than 750 h of training on topics as diverse as satellite meteorology, space weather, geodetic surveying, climate variability, numerical weather prediction, oil spill observations, and oceanography, to name a few. While weather and water topics remain COMET’s main focus, the program truly encompasses the wider area of environmental sciences.

COMET’s audience has expanded globally as it has become a critical resource throughout the world. Currently, more than 125,000 users, representing over 200 non-U.S. countries, have registered on MetEd. Many modules have been translated into other languages, as shown in Table 2.

For its international audiences, COMET has developed several unique products and has also adapted a number of lessons originally designed for U.S. audiences. For example, with funding from the Bureau of Meteorology of Australia, COMET designed a number of modules specific to Australian forecasting, including the module “Fire Weather Patterns in Australia: Southeast Australia” (www.meted.ucar.edu/training_module.php?id=986#.VKHWB__aAg). COMET also hosts residence and online international courses, such as an 8-day winter weather and mountain meteorology course given in October 2014 for Korea Meteorological Administration senior forecasters as part of preparations for the 2018 Winter Olympics (Brennan 2014).

PARTICIPATION IN THE GLOBAL WEATHER COMMUNITY. From its inception, COMET has been heavily involved in international activities to promote education and training. In the early 1990s, UCAR saw its mission as one of enhancing and extending “the capabilities of the university community, nationally and internationally; to understand the

Fig. 9. A still image from an animation illustrating a haboob, a dust storm caused by a convective downburst.
behavior of the atmosphere and related systems and the global environment; and to foster the transfer of knowledge and technology for the betterment of life on Earth” (UCAR 2014). Both UCAR and NWS leadership strongly encouraged COMET’s participation in the global weather community.

The COMET staff has been active for many years in the WMO, serving on task teams and expert panels, and COMET is a member of the coordinating committee for the Standing Conference of the Heads of Training Institutions of National Meteorological Services (SCHOTI). SCHOTI members provide guidance and assistance to other countries with fewer resources to develop their own training materials. In the next decade, meteorological organizations worldwide will need to train up to 10,000 new forecasters and upgrade the skills of an additional 4,000 currently employed forecasters (WMO 2014). At present, there is no capacity to do that in regions and countries that do not already have robust training programs. COMET is working with the WMO on a concept of a virtual global campus that would provide links to training available from any institution (e.g., MetEd).

Another long-term effort COMET has been involved in is the African Satellite Meteorology Education and Training (ASMET) project. ASMET produces online and CD-based learning lessons that teach African forecasters how to enhance their forecasts by making better use of meteorological satellite images and products. The lessons are developed by the ASMET team, which consists of meteorology instructors from several African forecast agencies and staff from EUMETSAT and COMET.

COMET staff have also been active members of the Community for the Advancement of Learning in Meteorology (CALMet) working group, which now reports to SCHOTI. CALMet’s purpose is to provide venues for meteorological educators and trainers to share experiences and ideas for applying emerging technologies and strategies. COMET was one of the initiators of CALMet (www.calmet.org/) and hosted the first international conference (as well as a later conference). These conferences help build international relationships that have a large impact on meteorology education worldwide.

LOOKING TOWARD THE FUTURE.

Although COMET is known primarily for its courses for operational forecasters, it has seen strong growth in other areas in geoscience and environmental education. That trend will likely continue as more agencies, the private sector, and nonprofits prepare for future challenges. In addition to its traditional role of developing training from initial concept to product rollout, COMET will provide a menu of specific services tailored to the requirements of its clients, including

- analyses of client needs and gaps in services that can be met with training.

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<td>Indonesian</td>
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1 Accessed via the Spanish version of MetEd (www.meted.ucar.edu/index_es.php).
media development,
• video scripting and production,
• instructional design consultation, and
• meeting and workshop facilitation.

On a larger scale, COMET and UCAR are working on a plan that in the next 10 years will provide virtual competency-based courses to support the development of professional workforces issuing and utilizing climate and weather forecasts. The vision is for a UCAR Center for Workforce Competency, which would organize materials and center content development on job tasks. A particular job responsibility would be analyzed to define the job duties involved, which would be further broken into the performance elements that must be accomplished to successfully complete the task (Fig. 11). Current training and education are often focused on developing knowledge, followed by an intense training period after a person is hired to do the job. Often the original knowledge is lost over time. In contrast, when knowledge is immediately applied to a realistic job task, retention increases. Competency-based learning is designed to use applied learning, information recall, and application in multiple job-related tasks in an academic environment, which will increase knowledge retention and develop job-related competencies before individuals arrive as new employees on the job. Training to support those elements would target the knowledge and skills required for the particular job duty and would be accessed via a single portal connected to a variety of hosted collections at different locations, including MetEd. Potential audiences include

• employees of national and international weather services;
• employees of federal, state, and local agencies whose missions are impacted by climate and weather events;
• universities and colleges interested in adding career-focused credentialing within their academic programs; and
• individuals seeking to improve their professional capabilities.

**FINAL THOUGHTS.** COMET was established 25 years ago to support the professional development of weather forecasters by improving their understanding of mesoscale meteorology and the uses of new weather technologies during the NWS’s modernization. Since then, it has become a world leader in innovating methods to disseminate and increase scientific knowledge in the environmental sciences for employees and students from many disciplines. COMET has been through many changes and will undoubtedly need to adapt to many more in the future. What remains constant is its commitment to deliver scientifically relevant and instructionally progressive products and services to enhance the performance of environmental forecasters and other professionals as well as to increase the knowledge of public users of environmental information.

**ACKNOWLEDGMENTS.** A foundational principle of COMET is that all of its activities are strengthened by collaboration with others. COMET’s primary community includes environmental forecasters and scientists in all settings, including universities, government agencies, state and local governments, and the private sector, both in the United States and internationally. We are grateful to all those who have participated in COMET activities for their involvement and support.

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