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Students of Purdue Observing Tornadic Thunderstorms for Research (SPOTTR): An Update

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1. Introduction

At Purdue University, atmospheric science undergraduate and graduate students in the Earth, Atmospheric, and Planetary Sciences (EAPS) department have consistently expressed a strong interest in working closely with professors on research projects involving severe storms. Leveraging this desire to enhance student learning of atmospheric science, an elective, four week-long, summer "severe storms field work" course was created within Purdue EAPS. Learning, in this context, is defined as, "the process whereby knowledge is created through the transformation of experience" (Kolb 1984).

The primary objectives of the Students of Purdue Observing Tornadic Thunderstorms for Research (SPOTTR) course, as originally formulated in 2016, were:

- For students to learn current severe weather forecasting and observation techniques;
- For students to have an authentic atmospheric science field work experience, using research-grade observing instruments, and opportunities to continue to work with these data if they chose to do so;
- To expose students to career paths in severe storms research and forecasting;
- To enhance their learning of severe storms forecasting and research through reflective journaling and other active learning exercises.

Six undergraduate students and three instructors (authors Tanamachi, Dawson, and Dr. Michael Baldwin) participated in the first SPOTTR course in summer 2016. After the end of the 2016 course, some of the undergraduate participants requested to continue working with the instructors, or sought them out for closer mentorship. These developments prompted us to more objectively evaluate the benefits of the course from a teaching and learning perspective, and effect beneficial changes in those areas that were deemed most likely to have positive impact on students' career aspirations in subsequent versions of the course. To this end, the 2017 and 2018 SPOTTR students (totaling seven undergraduates and six graduate students) were given two questionnaires, one at the beginning and one at the end of the course, that were designed to assess changes in their knowledge levels, confidence in scientific techniques, and career aspirations. We report these updated results following a description of the SPOTTR course design.

2. Course design

The SPOTTR course was designed to provide an experiential learning scenario (Kolb 1984). The Kolb (1984) experiential learning cycle (ELC) model consists of four phases: (1) *concrete learning*, in which the learner interacts with the environment; (2) *reflective thinking*, in which the learner compares their experience with his or her existing knowledge; (3) *abstract conceptualization*, in which the learner updates his or her conceptual understanding with insights gained through reflection, and (4) *active experimentation*, in which the learner translates his or her updated conceptual understanding into updated set of actions (Fig. 1). The cycle is then repeated to consolidate the students' understanding, a process Kolb terms the "experiential learning spiral" in the second edition of his 1984 text (implying that the learners' knowledge expands with each cycle). Severe storms forecasting and observation, which occurs in a daily cycle, lends itself naturally to this model.

In the context of this course, concrete learning (stage 1) consisted of students observing

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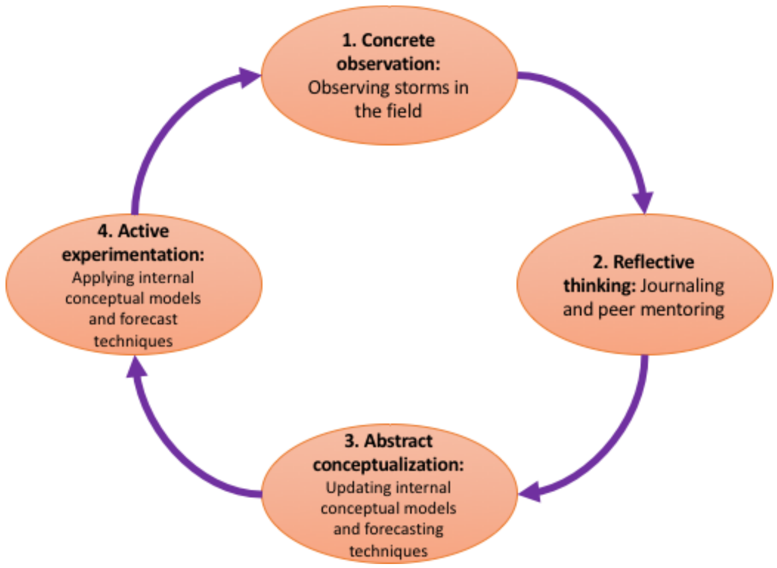

Fig. 1. Adapted conceptual diagram of the Kolb (1984) experiential learning cycle, showing which daily SPOTTR activities are associated with each phase.

storms in the field. Reflective thinking (stage 2) consisted mainly of a self-directed reflective journaling exercise (described below) in which students compared the observed storm to the forecast generated by the group that morning, contemplating factors that may have led to imperfections in the forecast, such as problematic numerical weather forecasts or inaccurate internal conceptual models of storm behavior and evolution. Students were encouraged to discuss their insights informally amongst themselves (peer mentoring). Students were directed to distill their "lessons learned" (abstract conceptualization, stage 3) and update their forecast technique the next day based upon these lessons (active experimentation, stage 4). By repeating this cycle over several consecutive days of the trip, it was hoped that an experiential learning "spiral" would be established that would enhance the students' learning of severe weather forecasting and result in improved forecasting technique.

Purdue's SPOTTR course was taught by two of the authors (Dawson and Tanamachi) in 2017 and 2018. Because of budgetary and transportation constraints, the SPOTTR course was limited to eight students in both years. The instructors admitted students based upon essay responses to a brief intake questionnaire (Barrett and Woods 2012). The essay questions assessed students' intrinsic motivation to learn (Keller 2010). For most students, their primary intrinsic motivator was their desire to personally observe a tornado, a relatively rare and powerful atmospheric phenomenon. The students were also motivated to a lesser degree by other, longer-term benefits: opportunities to visit sites deemed beneficial for their professional development, meeting atmospheric scientists specializing in severe weather forecasting and research, online and in-person interaction with National Weather Service personnel, and the procurement of new, original data sets that the students could use in subsequent projects and classes.

The approach of taking atmospheric science students on an extended spring field excursion to Tornado Alley to forecast and observe severe storms is not new. The reader is referred to Godfrey et al. (2011) and Barrett and Woods (2012) for summary listings of such courses taught at different institutions and comprehensive educational justification. Typically, such courses contain six to twenty students. The participants (students and instructors) travel to Tornado Alley in one or more large passenger vehicles, each containing at least one experienced instructor, who guides the students as they select a target storm to intercept and observe safely. The principal differences between our course and previous ones are (1) our deliberate integration of a suite of research-grade meteorological instrumentation and (2) active dissemination of meteorological observations obtained with that equipment to operational and research meteorologists in near real-time. These activities support of all four stages of the Kolb (1984) ELC.

During the first two weeks of the four-week course, students completed storm spotter training (Moller 1978), which was administered in person by a National Weather Service employee, learned the ingredients-based method of severe weather forecasting (Johns and Doswell 1992), were taught basic radar interpretation skills, and were oriented to each of the meteorological instruments to be used (Fig. 2). The instruments used in this course have historically been used in severe weather field programs. They included:

- The University of Massachusetts X-band, mobile, polarimetric Doppler radar (UMass X-Pol) (Bluestein et al. 2007; Tanamachi et al. 2012), for collecting volumetric observations of potentially tornadic storms (Fig. 2; 2017 only).
- The University of Massachusetts Low Power Radar (UMass LPR; Heberling et al. 2017; Tanamachi et al. 2018), for collecting rapid volume scans of potentially tornadic storms (2018 only). The 2018 SPOTTR course was the first time the UMass LPR was fielded for severe storm observations; preliminary results will be presented elsewhere at this conference (Tanamachi et al. 2019).
- A Sparv Embedded brand Windsond radio sounding system, for recording thermodynamic and wind profiles in the lowest 9 km AGL of the atmosphere (Fig. 2).
- Portable In Situ Precipitation Stations (PIPS) (Dawson et al. 2016) for measuring drop size distributions in the hook echo region of supercells.
- The Kestrel 4000 Pocket Weather Tracker, a handheld meteorological measuring device, to quickly record surface observations in the field.

Prior to the trip, students received training on the operation of the instruments. Each student was issued a Kestrel, and was expected to carry it with them at all times for impromptu measurements in rapidly changing conditions. Moreover, each student was expected to attain "mastery" (defined here as the ability to operate the instrument from startup to shutdown with minimal to no assistance from the instructors) of at least one of the larger instruments (e.g., the mobile radar, radiosounding system, or PIPS). In our experience, that students naturally gravitated to one or two instruments, were eager to attain mastery, and by the end of the trip, had self-designated primary and backup operators for each instrument.

In addition to their personal reflective journals, students were also charged with logging each deployment. Log templates were supplied for each instrument and were filled out by students during each deployment. These logs became part of the metadata for the project.

Fig. 2. The SPOTTR 2017 instrument training session. Instructor D. Dawson, holding the balloon, instructs student J. Gable on proper sonde release technique. A PIPS can be seen in the foreground, and the UMass X-Pol radar truck is parked behind the group. From left to right, participants are P. Saunders, S. Simmons (hidden), J. Gable, A. LaFleur, instructor D. Dawson, K. Popp, and instructor R. Tanamachi. Photo courtesy of T. Uhlman.

Students were asked to keep a daily journal of each day's activities, which included the morning forecast, the meteorological rationale for selection of the target area, a time log of events during deployments, details of the deployments, meteorological observations. It was emphasized that the journals should be updated in near real time and be as detailed as possible to mitigate degradation of personal memories. At the end of each day, students were asked to dedicate 15-30 minutes to filling in any gaps in their event sequences, reflecting on the accuracy of the group's morning forecast, and contemplating ways their forecasting technique might be improved. They also prepared questions to bring to the instructor at the next morning's briefing. This reflective journaling task was rooted in the second and third stages of the Kolb (1984) experiential learning model (reflective observation and abstract conceptualization), with the intent of compelling self-directed learning within each student.

The students then traveled west from Purdue University to “Tornado Alley” in the central United States – a region climatologically favored for severe weather occurrence in May and June – for a period of seven days. The group operated in a nomadic fashion, assessed the conditions and potential for severe weather on a daily basis, and traveled to areas deemed favorable for supercells. Each day of the trip, the class followed a scheduled routine (Table 1) designed to emulate those used during severe weather research programs in which the instructors had previously participated, such as VORTEX2 (Wurman et al. 2012; Tanamachi et al. 2013) and VORTEX-Southeast (Dawson et al. 2016; Koch 2016; Rasmussen and Koch 2016; Tanamachi et al. 2016). The day started with a weather briefing led by pairs of students, in which they discussed the potential target areas and their rationale for selecting them. The team would then ferry (if necessary) to the selected target, and commence preconvective radiosonde launches. Once storms had formed, the students and instructors coordinated deployment of the PIPS and mobile radar, as well as additional soundings if time permitted. For safety reasons, operations ceased at sunset. Once lodging was obtained, the students spent 15-30 minutes writing in their reflective journals.

On days when convective storm potential was considered negligible by the forecast team, or any target areas were prohibitively distant from the group’s morning location (> 600 mi), the group would instead attempt to visit to locations of interest deemed beneficial to the students’ professional development; for example, the National Weather Center (NWC) in Norman, Oklahoma. This alternate activity served the course objective of expanding the students’ career aspirations and awareness.

A public Twitter account (@eaps_spottr), registered with Purdue University, served as the official communication portal for the class. The account home page featured a class photo (updated each year), a brief description outlining the group’s mission, and featured the activities of the participants. Instructors had the ability to post original content and to retweet posts from the students’ personal Twitter accounts. Content consisted mainly of photographs taken in the field and screenshots of collected data, such as radar images or skew-T log-p diagrams of soundings (e.g., Fig. 3). By the conclusion of the 2018 field trip, the SPOTTR Twitter account had more than 190 followers, and was regarded as a high quality information source by local NWS offices (e.g., Fig. 3).

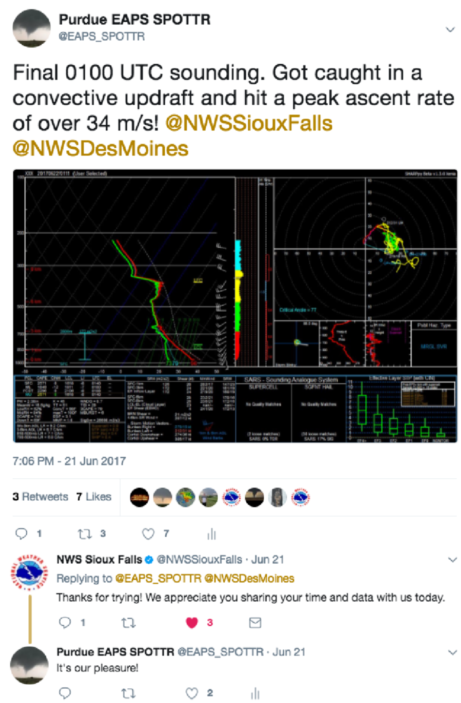

Fig. 3. Example of a tweet sent from @EAPS_SPOTTR containing an analyzed skew-T log-p diagram from a radiosonde sounding launched by the SPOTTR students from Sioux City, Iowa on 21 June 2017, and responses from two NWS entities (NWS Sioux Falls, South Dakota WFO and NWS Des Moines, Iowa WFO). The skew-T log-p diagram was generated using SHARPpy (Blumberg et al. 2017).

Owing to logistical issues that forced the 2017 SPOTTR field trip to occur in mid-June, faced a challenging quiescent weather pattern, and struggled to find conditions even moderately conducive for supercells. No tornadoes were observed by this group, but they were able to visit multiple professional development sites (the NWC, and the University of Alabama Huntsville SWIRLL building). In 2018, the SPOTTR group trip occurred during the last week of May instead. This group was more successful at collecting observations in supercells, and observed dual landspout tornadoes near Flagler, Colorado on 28 May. The 2018 class participants were also able to visit the NWC and the OU Radar Innovations Laboratory (RIL) in Norman, Oklahoma (Fig. 4).

Table 1. A typical day's schedule for the SPOTTR class on days with convective storms.

Time (local)	Activity
9:00 a.m. – 10:00 a.m.	Student-led weather briefing
10:00 a.m. – 2:00 p.m.	Drive to target area (if necessary)
2:00 – 4:00 p.m.	Preconvective observations: • Soundings • Surface observations with handheld weather meters
4:00 – 6:00 p.m.	Observations of convective initiation: • Soundings • Radar observations over volumes spanning convective tower depth • Surface observations with handheld weather meters
6:00 – local sunset	Observations of deep convective storms: • Soundings • Drop size distribution measurements with disdrometers • Storm-scale radar observations over volumes spanning storm depth (up to 12 km AGL) • SWIR imaging of convective thunderstorm cloud bases (2016 only) • Surface observations with handheld weather meters
After sunset	Adjourn to hotel, complete logs / journals


Fig. 4. Dr. David Bodine (right) introduces the 2018 SPOTTR class to the PX-10000 radar at the OU Radar Innovations Laboratory.

The course participants returned to Purdue University at the conclusion of the field trip. During the fourth and final week of the course, students worked in pairs to perform retrospective case studies of the individual days of the trip. Each was asked to articulate what they learned about the complexities of severe storms forecasting and intercept activities using the case day as an example.

A final, ancillary activity was a "career gallery walk" (Fig. 5), conceived as a means by which students could learn about different possible career tracks in meteorology. Short professional biographies were solicited from about a dozen of the instructors' contemporaries, most of whom had completed their terminal atmospheric science degrees a decade or more prior. The bios briefly described what those individuals had done in their professional lives. They represented diverse career tracks spanning academia, civil service, and the private sector, with a special emphasis on unusual or nontraditional career tracks. Students inspected these bios and were invited to ask questions of the subjects, to which responses were gathered and disseminated to the class electronically.


Fig. 5. The career gallery walk, in which students read short professional bios of persons collected approximately 10 years after receiving their terminal atmospheric science degrees.

3. Questionnaire responses

The SPOTTR students were given two surveys, one at the beginning ("pre") and one at the end ("post") of the course. The survey was based upon the instrument described by Adedokun et al. (2014), and was designed to assess changes in students' research skills, confidence in field work techniques, and career aspirations. Additionally, the 2018 class participants were given the "Content and context quiz" of Barrett and Woods

(2012) (i.e., their Table 5) in order to assess changes in their knowledge levels.

Of the 13 respondents, six were graduate students, six were undergraduates, and one was a non-degree-seeking student. Five respondents identified as female and eight as male. Ten of the students specialized or majored in atmospheric science, and three specialized in non-atmospheric science areas.

The findings are not generalizable to all populations of atmospheric science students due to the limited sample size, but the sample is representative of the students in this course and the findings may be transferrable to other teaching contexts with similar student populations. We offer these tentative findings:

- **Incorporation of research-grade meteorological instrumentation into the SPOTTR course was beneficial.** All 13 students either strongly agreed or agreed with the statement, "**The use of research-grade equipment enhanced my research experience**," and indicated that the field work had contributed either "a good amount" or "a great deal" to their SPOTTR experience. We intend to continue giving students hands-on experience using research-grade instrumentation whenever possible during this course.
- **Students' understanding of severe weather and severe weather forecasting improved.** The 2018 students (n=8) were given a set of basic weather forecasting competency questions taken from Barrett and Woods (2012) at both the beginning and end of the course. As an example, the mean score for the question, **"What are the necessary ingredients for supercell formation?"** increased from 38 to 82 out of 100 points between the start and end of the course. Additionally, all 13 students either strongly agreed or agreed with the statement "**The forecasting exercises improved my understanding of severe storms meteorology**."
- **Professional site visits and career awareness activities were valuable to most students.** All but three students indicated that visits to sites like the NWC, OU RIL, and SWIRLL had contributed either "a good amount" or "a great deal" to their SPOTTR experience. It is not clear why the professional site visits were less valuable to the remaining students, but it is noted that three of the students were not atmospheric science majors, so perhaps the site visits were not as relevant to them. Most students also indicated their awareness of career opportunities available to them, as well as career tracks that they could specialize in, had improved as a result of the SPOTTR course.
- **Reflective journaling helped students consolidate and retain the material**. All 13 students indicated that their skill at keeping a daily journal of the day's events had improved, and 11 of them strongly agreed or agreed with the statement, "**My SPOTTR journal helped me clarify my thoughts about my experience.**" In written responses, students reported that journaling helped them remember details, organize their thinking, and connect principles learned in the classroom to the severe weather forecasting scenarios that they encountered. One student wrote, "Even with proper preparation, it's very possible that there are days chasers may be shut out, or choose the incorrect storm to follow, so the reflection done in the journal is useful for determining what went wrong that day, and how to improve on forecasting in the future."

Based on student feedback, the instructors are considering modest changes to the course design in the following areas:

- **Students have expressed a desire for greater responsibility for the forecasting and deployment decisions.** The instructors currently hold veto power over the students' choice of a target area. By ceding this responsibility entirely to the students, the students would ultimately become responsible for the group's collective success or failure to observe tornadoes. While this would give students a greater stake in the quality of their forecasts, some of the research equipment being used in this course is funded through external grants to the instructors, and as such it is expected that the instructors will be in control of the observations and deployments. It remains to be seen whether a compromise can be reached between these two competing interests. However, instances where students and instructors have disagreed about the choice of a target have thus far been relatively rare.

- **Extend the field trip to 10 to 14 days, likely by having the students bear more of the cost burden.** Students almost universally requested that the trip be made longer, even if it means that they have to pay more to participate. (Currently, all but a modest amount of the transportation and lodging expenses for each student are borne by the department, and the instructors have waived their summer teaching salary for this course.) The current budget limits the trip to seven days, which is just long enough that each pair of students can lead one forecast discussion. Extending to at least 10 days would allow each student pair to lead two forecast discussions, allowing the instructors a chance to give the students feedback and improve the second discussion. Additional funding is the only feasible avenue that will make this extension possible.
- **Maintain a late May time frame for the field trip.** In 2017, the course trip was held relatively late (mid-June) owing to logistical issues, by which time the Great Plains region was under a persistent, convection-suppressing, high pressure ridge. The students had a very difficult time finding severe weather to target. Therefore, the late-May / early-June time frame for this course should be maintained whenever possible.
- **Visit professional development sites with foci other than atmospheric science,** such as NASA, DOE, or DOD sites. Again, such additions would likely require additional travel funds, and more costs to be borne by the student. Some of these places may not be available for impromptu or walk-in tours, requiring the instructors to establish relationships with staff at those centers ahead of time.
- **Make the career exploration component more interactive.** Rather than having students review static printed professional biographies in a "gallery walk" (Fig. 5) and interact with the subjects by instructor-moderated email, the instructors will have the students read the biographies beforehand, and then request that two or three of those individuals participate in a live webinar panel during the fourth week. This change will allow the students to interact directly with the subjects on a more personal level.
- **Actively solicit storm chaser interactions with the SPOTTR group during the field trip.** Some students requested more time to meet and interact with more storm chasers in the field, other than those engaged in scientific research (e.g., hobbyists, photographers). Because SPOTTR is an atmospheric science field work course run by a science department, the emphasis must remain on teaching science. However, the instructors are amenable to actively soliciting interactions with storm chasers in the field in addition to those that occur incidentally (which are actually quite common).

4. Conclusions and recommendations

A new course has been developed at a major midwestern research university that leverages students' desire to see tornadoes as an intrinsic motivator for learning severe storms forecasting and field work techniques. The course design is grounded in established pedagogical theory, and novel in that it incorporates hands-on experience using research-grade meteorological instrumentation. Based upon the students responses to pre- and post-course surveys, we conclude that the course is a valuable addition to these students' atmospheric science education experiences, and that every effort should be made to continue it into the future. In particular, student responses indicate improvements in understanding of severe weather forecasting, severe storms-related field work, and meteorological instrumentation. Student comments almost universally conveyed enthusiasm about the course overall.

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