The CAR Approach: Creative Applied Research Experiences for Master's Students in Autonomous Platooning

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***Abstract*— Autonomous vehicles (AVs) are crucial robotic systems that promise to improve our lives via safe, efficient, and inclusive transport–while posing some new challenges for the education of future researchers in the area, that our current research and education might not be ready to deal with: In particular, we don't know what the AVs of the future will look like, practical learning is restricted due to cost and safety concerns, and a high degree of multidisciplinary knowledge is required. Here, following the broad outline of Active Student Participation theory, we propose a pedagogical approach targeted toward AVs called *CAR* that combines *Creativity* theory, *Applied* demo-oriented learning, and *Real* world research context. Furthermore, we report on applying the approach to stimulate learning and engagement in a master's course, in which students freely created a demo with 10 small robots running ROS2 and Ubuntu on Raspberry Pis, in connection to an ongoing research project and a real current problem (SafeSmart and COVID-19). The results suggested the feasibility of the CAR approach for enabling learning, as well as mutual benefits for both the students and researchers involved, and indicated some possibilities for future improvement, toward more effective integration of research experiences into second cycle courses.**

I. INTRODUCTION

The current paper explores how we can train and engage the next generations of researchers in autonomous vehicles (AVs), with a particular focus on enabling creative, applied research experiences "early on" for master's students.

Various kinds of robots are being designed to save time and money, and otherwise improve the quality of people's lives, in line with ideas like the UN's Sustainable Development Goals and the Industry 4.0 revolution [1], [2]. One exciting topic concerns AVs, which promise to play a key role in emerging smart cities via safe, efficient, and inclusive transport. An AV is a self-driving or robo-car that uses sensing, communication, and control to move safely with minimal human input, as described in SAE's automation level standard $J3016_201609$.[1] To realize this scenario, there is currently a demand for an increased workforce in this area, which could be met by expanding education opportunities. However, when training students to become AV researchers, some challenges arise: (1) We don't know what the AVs of tomorrow will be like; they are expected to not merely be newer versions of the systems we are using today, but to involve new opportunities and challenges that our engineering research and education are currently not designed to address [3]. (2) AVs are hard to study, since vehicles are expensive and can be dangerous. (3) A high degree of both breadth and depth of knowledge are required, in various research fields such as communications, control, localization, testing, and integration.

To address these challenges, we propose here a pedagogical approach–following the broad outline of *Active Student Participation*, based on general insights in the literature and our own ideas about AVs–which we call *CAR*:

- C (Creativity): New opportunities and challenges can be envisioned following a process that does not exclude students based on ability.
- A (Applied Demos): Prototyping can be used to stimulate students' ideation in a safe and inexpensive manner.
- R (Real World Context): Engaging in real research concerned with current topics–even in small steps–can provide meaning and engagement, to motivate learning of complex topics and continuation in the area.

Active Student Participation refers to a threshold concept in academic development that can take various forms, but one commonality is that students take a more active role in their education, often through partnerships [4], [5]; in CAR, the students are active in applying their creativity within an assigned group research theme, which follows a tight coupling between education and research. The proposed approach is described in more detail below, and we also report on a case study example in a master's course later on, as well as some insights and feedback, toward stimulating thought about integration of effective learning approaches for AVs into second cycle courses.

A. Creativity

Creativity is a fundamental cornerstone of learning and research; teachers want their students to be creative, and research has been defined as "creative work undertaken on a systematic basis in order to increase ... knowledge".[2] Some challenges with incorporating creativity into education include lack of time for both students and teachers, overloaded curricula, difficulties in assessing creativity compared to fixed tasks with known solutions, differences in how teachers and students perceive tasks, and misconceptions that creativity can be associated only with the arts or with a

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[1] https://cdn.oemoffhighway.com/files/base/acbm/ooh/document/2016/03/j3016.pdf

[2] http://www.oecd.org/sti/inno/Frascati-Manual.htm

few of the brightest students [6]. Such reasons may account for why engineering courses typically do not emphasize creativity, despite its importance and prevalence in actual engineering [7]. Accordingly, the widely-used Structure of Observed Learning Outcomes (SOLO) and revised Bloom's taxonomies both place creative learning at the far end of the knowledge spectrum representing the advanced level of thought ("extended abstract" or "creating") [8], [9]; from this perspective, creativity is desired but difficult to attain. At the same time, creativity has been described, not as an intrinsic characteristic that a person has or does not have, but rather as a way of doing things that can be either fostered or suppressed by one's learning environment [10]. Also, creativity encompasses ideas that are new either for a person (personal creativity or "P-creativity") or for all of humanity (historic creativity or "H-creativity") [11]; i.e., P-creativity is also H-creative if it involves conceptualization or creation that has not been carried out by someone before.

Here, we suggest that there is a potential contradiction that could lead to confusion: It seems as though we want our students to be creative but expect most of them not to be. Especially in the context of AVs, where there is much content to learn, we believe that it might be counterproductive to pigeonhole creative learning as the hardest form of learning (i.e., considering only H-creativity, and not the process), such that creativity will likely be the first goal that students give up on.

Therefore, in the CAR approach, we explore the use of "creativity" in two ways. The first relates to goals and learning activities. We *"invert"* the SOLO/Bloom order to place creativity at the *beginning*, such that all students in a course must engage in a creative process. In other words, the students' task is to learn as if they are aiming to provide an "extended abstract", to stimulate them; here, the goal is more related to the process than the outcome. [3] The second usage of creativity is as a dichotomous grading criterion. For example, students at the end of a course can submit a grading proposal in which they describe how they have been creative, which is evaluated by the teachers. We note that this suggestion does not entail that creativity should be the only grading criterion; rather, it can be an accessible path toward attaining a good grade for active, motivated students who might have some gaps in their knowledge. Thus, a student can get a higher grade with very slight H-creativity, or high P-creativity. Although it might seem difficult to evaluate creativity, the heart of creativity is novelty [10], teachers usually also conduct research, and researchers often must evaluate the novelty of research manuscripts; also, in practice, creativity can be clearly demonstrated (e.g., if a student comes up with their own idea, versus just reporting the contents of a paper).[4]

[3]We note that "extended abstract"-level knowledge might not be desired for all tasks or courses, but rather just where depth is desired.

[4]Other alternatives exist, such as applying Guilford's metrics of fluency, flexibility, and originality to evaluate creativity as divergent thinking [12].

B. Applied demos

Demos offer benefits: Students can actively apply knowledge and make concepts their own in a "hands-on", engaging and sustainable manner, that combines the benefits of project-based learning and problem-based learning, action learning, playful simulations, cooperative learning (if one student "wins", everyone "wins") and the experiential approach [13]. Group work builds on social learning and situated learning, and backcasting is allowed, in that students can think how to go backward from some desired future scenario to implement their demo [14].

Here, we point out a potential contradiction: there seem to be benefits if we constrain students to work on practical tasks for demos, that could stop them from being creative and exploring theoretical tasks. Therefore, we propose that shared demos should be presented not as a goal in themselves, but as an inclusive starting point and "seed" from which either practical or theoretical learning can grow, and as a scaffolding framework that reduces the space of possible ideas from being prohibitively large while still leaving many possibilities open. From the perspective of the CAR approach, we believe that there is an especially good fit, since AVs can be modeled by small robots, which are highly "demoable": engaging, inexpensive, safe, portable, and easily available. A demo could also be used as a showcase for the students' learning that becomes visible to prospective employers in the field of AVs after graduation–as well as a source of pride and a way to render concrete their learning achievement. As well, some hype in AV-related fields like artificial intelligence can be avoided or clarified by showing concrete examples of what is currently possible, also in line with the maxim, "Demo or die". Moreover, we propose that there is value in shared demos not only for students but also for researchers, which can act as a flexible prototype or microcosm, to reveal real world problems or allow brainstorming in a rapid but informative manner.

C. Research

Research experiences (REs) are seen as valuable for students to develop creativity and critical thinking, which could greatly influence their identities and future directions–in line with the prescriptions of research-oriented teaching and research-based learning [15], inquiry learning [16], and more generally legitimate peripheral participation and communities of practice [17]. Thus, there is a trend to encourage students to participate earlier in REs, with various work focusing on undergraduate and high school students. On the other hand, aside from optional internships, master's students often only have REs just before graduation when conducting the master thesis; worth many credits, the thesis typically requires engagement in some commensurately long and complex research task, leaving little time to produce shorter academic papers that might be more widely disseminated. Conversely, regular master's courses can focus only on students' learning: students do development work that is lost when a course finishes, and there is little care from the wider community about what is created and lost. In short, a perception that research is long and arduous could obfuscate ideation on how it could be incorporated into regular courses.

Thus, we highlight this potential contradiction: we are offering REs to ever younger and less experienced students but typically not in regular master's courses, where it might be easier to do so. From the perspective of the CAR approach, we suggest that a tight coupling between education and research would be useful, since AVs are not yet a widespread reality: research offers an important opportunity for students to engage in learning on meaningful tasks and construction of knowledge that can be of interest and use to a greater community of researchers; this feeling of doing something meaningful and being connected to others could help students to become motivated to continue in research and development in challenging fields like AVs.

One way to help students to engage in such REs could be to formulate research in small focused ”steps” or chunks that are easier to complete: We base this idea on the concept of ”prototyping”, which allows design researchers to focus on key features to obtain fast results, as well as the possibility to divide responsibilities in a group, and the observation that there is a strong precedent for the presentation of engineering research in a short format, even at high levels (e.g., Letters in Nature or Science). Furthermore, we suggest that the difficult task of selecting a research problem can be accelerated by linking courses to research projects, and drawing inspiration from the future work sections of published papers. Students should not be restricted to these ideas, but rather they can act also as “seeds” to inspire the students and give them an idea about what is feasible or expected; moreover, researchers should not be required to spend much time with hand-holding or spoon-feeding, which would be counterproductive, in hindering rather than helping progress in the field of AVs.

D. Examples of Related Courses

Creativity, applied demos, and real world context have been incorporated previously into learning experiences. For example, creativity has been fostered by offering various modular parts in LEGO robotics, allowing students to freely build a vast range of imagined scenarios, from sumo-bots to soccer, maze solving, bubble blowing, robotic animals, miniature golf courses, haunted houses, dance robots, musical instruments, and puppet shows [18]. Furthermore, creativity was enhanced in software engineering courses with 500 students using ”software theater”, which incorporates techniques borrowed from theater and film such as props and humor [7]. However, AV courses tend to specify the tasks that students must complete, presumably to deal with the high challenges of designing capabilities like sensing and navigation.

Demonstrations involving small car robots racing have also been included at the ends of some courses. For example, Karaman et al. report on a race between some small MIT RACECAR robots programmed by 46 high school students [19]. Likewise, Raman et al. described three small F1tenth robots that navigated a racecourse at the end of a course with 14 graduate students; notably, the authors followed a five-step pedagogic approach (motivate, demonstrate, explain, allow experimentation, and review) which also involved demonstrations from the teachers' side [20]. Various other platforms have been incorporated into demonstrations, such as Epuck, AWSDeepRacer, and Quanser Q-Car, which are compared by Vincke and colleagues; a take-away message, in designing a small scale model with a CAN bus with six students, is the importance of creating more realistic scale models [21]. We did not find a report about the kind of demo we envisioned: a persisting demo being refined in *tollgates* throughout a course, that required student groups to collaborate to achieve typical AV capabilities such as collision avoidance at intersections and platooning.

Moreover, connections to real-world situations, that empower students to define and tackle problems that influence their lives, appear to be lacking in robotics education [22]. Although researchers and developers often seek to identify real problems by involving stakeholders, in AV courses the focus can be more on the high technical challenges. Also, we are not aware of any integration of small research steps from an ongoing research project into AV courses, again presumably due to the perceived high challenge, as well as stigma related to research that doesn't ”fit” typical size expectations.

Thus, there appeared to be a gap relating to the integration of creativity, applied demos, and real world context in AV courses, which we seek to tackle via the conceptualization of the CAR approach.[5]

II. Methods

To gain insight into how the approach would fare in practice, thereby fitting some empirical ”flesh” to the bones of our ideas, we investigated implementing the CAR approach in a course and obtained feedback.

A. Set-up

Out of a number of AV-related research projects that the authors are involved with, the SafeSmart research project was selected, which is a four year project investigating safe, reliable cooperation between autonomous vehicles, infrastructure, and vulnerable road users within general urban streets. Increasing automation levels entails enhanced challenges, complexity, and safety and security requirements for such systems that would allow for general social acceptance and trust. Toward this goal, SafeSmart aims to develop technical advances in sensing & localization, communication & collaboration, and decision & control–as well as high-quality, high-confidence, and time-efficient testing and integration.

Furthermore, we selected an engineering course called ”Design of Embedded and Intelligent Systems” (hereafter DEIS; running from Sep. 2020 - Jan. 2021), offered at our university in southern Sweden. As a course for second year students just before the thesis, it was guessed that there would be a higher chance of being able to successfully

[5]Our previous work indirectly touched on some ideas related to these topics, but focused on a different topic, of exploring the use of a behavior model to scaffold learning ROS [23].

engage in research than in some other courses related to AVs in the first year.

B. Students

22 course students took part (age: average: 27.2 years, SD = 3.6; 5 female, 17 male; from 6 countries, with India, Sweden, and Germany most common). Two of these students were registered but dropped out for personal reasons at the start of the course, leaving 20 active students. All students were enrolled in a computer science and engineering programme and, when asked to briefly describe their backgrounds, mentioned electronics (12 students), programming (11[6]), communication/networking (5), hardware (3), embedded systems (3), and signal processing (2).

C. Procedure

The CAR approach was applied:

Creativity. In the spirit of mutual trust and respect, students were given high autonomy, and were free to use a broad variety of design approaches, learning platforms and collaborative software, whiteboards, and space in the course project room. Lectures contained some critical thinking exercises, and active participation and "risk-taking" were encouraged, in the sense that students were invited to speak in class and ask questions of others, while accepting divergent thinking and differing ideas; reflection also occurred regularly in project tollgate reports.

Demo. To facilitate applied learning, all parts were left in the project room for the students to freely use, from the start of the course. Two small robots were given to each group of students, a Sparkfun Redbot[7] differential drive robot controlled by an Arduino microcontroller[8], and Ryze Tello drone[9], along with Raspberry Pi 4 (RPI) microcomputers[10] and various hardware components that the students required or could pick and choose. We wished to offer a high robot-to-human ratio to encourage active participation, also as there are some indications that use of more robots can have positive effects in some situations [24]. For communications, RPI 4 provides 2.4 GHz and 5.0 GHz IEEE 802.11B/g/n/ac wireless connectivity, as well as Bluetooth 5.0 and Ethernet. Assembly required various work designing circuits, which was supported by equipment, from computers and soldering irons, to 3D printers, multimeters and oscilloscopes. The software setup involved Ubuntu, ROS2[11] for communication, and OpenCV[12] for image processing. Fig. 1 shows a basic architecture for the course project. As well, prototyping materials such as cardboard and Lego blocks, and various extra parts like traffic cones and signs and electronics, were made freely available.

Research. Eight researchers (four in SafeSmart) took part as teachers in the course, giving classes and providing

[6]This includes four who mentioned Java and three who mentioned C/C++
[7]www.sparkfun.com/products/12649
[8]www.arduino.cc
[9]https://www.ryzerobotics.com/tello
[10]https://www.raspberrypi.org/
[11]https://docs.ros.org/en/foxy/
[12]https://opencv.org/

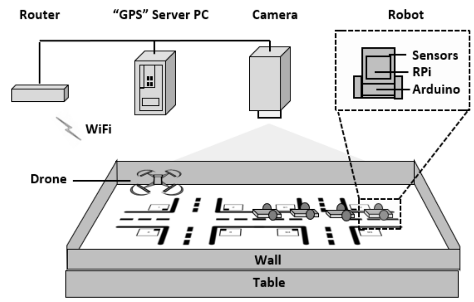

Fig. 1. Project environment: robots interacted on a table in the project room, within a "cityscape" with streets and buildings, and below a camera

opinions on topics related to their specialization; this also helped the students to see from different perspectives and know what is ongoing research in each area. (The researchers generally had low time involvement in the course, and fewer or more researchers could have been involved.) The lecture content related to research was intended to promote critical and independent thinking without stifling students. Research themes were directly obtained from the division of tasks in the SafeSmart research project; namely, the five themes were Localization, Communication, Decision and Control, Testing, and Integration. The students freely formed five groups of 4-5 members to work on each theme (although as noted, two students dropped out). For each area, some suggestions were drawn from the future work sections of the first published papers in the project. Some suggestions required expensive equipment such as radars and cars, and thus were adapted to the context. Students selected themes as groups, and conflicts were resolved through discussion.

CAR. Each of the three elements of CAR was contained in the project grading criteria: a grade of "3" was offered for applying basic course ideas within the group on the demo and individual research step, "4" if moderate P- or minor H-creativity were also demonstrated, and "5" if excellent methodology was further shown that resembled methods being used in the real world (3 is the lowest passing grade, and 5 is the highest). Thus, novelty and rigor were considered, which are also typical criteria for judging the quality of research.

D. Tasks

Based on a group's research theme, each student thought of and implemented their own "research step", proposed in an exam event. The outcomes of the research steps were then presented during a subsequent exam event, through either a slide presentation or physical demo, according to some research-related criteria.

The students carried out the course work in four tollgates: (1) system modeling, (2) initial research step presentation, (3) basic control and communication, and (4) final presentation, with platooning and collaboration. For (3) each group had to build one emergency vehicle (EV) and one regular vehicle and demonstrate basic motion control within lanes and ROS2 communication. (4) involved presenting capabilities related to the finalized research steps, the project theme (COVID-19), collaboration with other groups, and platooning (e.g., lane changing, formations, and changing the leader).

What was unclear to us in applying the CAR method was, could the students carry out their tasks in the time allotted by a regular course? And, what kind of benefit, if any, could students and researchers in the SafeSmart project receive?

III. Results

To estimate the usefulness and feasibility of the proposed approach from the student and researcher perspective, a simplified analysis was conducted through the lens of the CAR approach, alongside a survey and prototyping exercise.

In general, learning seemed to have been enabled. All groups completed their required tasks, also conducting 20 small research step tasks, which led to learning, as detailed below, that was shared with the class over several occasions:

Localization. Our suggestion was that the students in the localization group explore sensor position- and angle-invariance in ultrasonic (US) and infrared (IR) sensor arrays, and localization of robots in occlusions. In response, the group came up with their own scenario of sensing via cameras, thermal cameras, or microphones in poor weather. This involved comparing four approaches for trilateration (inferring a robot's location from its distance to landmarks), proposing combining dehazing with edge detection for robust marker detection, discussing challenges of thermal detection of robots (e.g., covered areas, varying material emissivities, temperature-related conditions like snow or hot ash, and electric vehicles), and exploring the use of sounds to detect ten urban contexts (e.g., car horns, children playing, construction sounds) via a neural network.

Communication. We suggested simulating various kinds of attacks from malicious users and proposing approaches for prevention, as well as exploring metrics for communication interference. The group proposed detecting a platooning Man In The Middle (MITM) attack via proximity with a deep neural network, observed reduced performance (frequency of messages) due to interference in publishing messages from more senders to a ROS2 topic, and proposed a modified vehicle interconnection metric usable with low memory requirements.

Decision and control. Our suggestion was to look into related ISO standards, develop the capability for robots to go to the side of the road to let an EV pass (possibly in tricky cases with parked cars), and explore safe and efficient acceleration on a time-varying slope. The group had fewer members due to the students who left the course, but set up some practical capability for communicative adaptive cruise control; this involved an inertial-based acceleration model (tested on a ramp comprising various slopes in the cityscape), which was also connected to the thresholded output of an US sensor.

Testing. We suggested investigating model-based testing, using weights/probabilities rather than boolean assertions for model transitions, and automata learning for automatic building of fault models. The group explored model-based testing in a simulation, in which robot behavior was controlled by generating COVID-19 patients to be picked up, at random locations, as well as in a physical prototype of an intersection management scenario they developed, using an overhead drone to facilitate passage of an EV.

Integration. Our suggestion, revolving around the concept of a smart traffic light, was for the students to create a dynamic control protocol to determine the best moment/distance to activate traffic lights, by modifying a toy traffic light to be programmable. The group followed this suggestion, connecting US sensors and cameras to neural networks to detect EVs and traffic status, which was used to heuristically control the traffic lamp over a ROS2 channel.

A. CAR analysis

The students' work was analyzed through the CAR lens, indicating that the proposed approach seems to have supported the students with moderate success at all three levels:

Creativity. The CAR approach allowed students the freedom to come up with their own ideas for the research steps; e.g., the poor weather scenario, the idea of using proximity to detect an attack on a platoon, the simulation of picking up patients, etc. The students also conducted some extra, creative activities not linked to any particular research step, which included using AruCo markers (at the class level) instead of spiral markers we provided, augmenting a drone to move its camera below rather than on the side, attaching emergency lights and sounds to robots (or a car-like facade), and manufacturing a broad range of buildings (with 3D printing, images of small inhabitants, and landing pads, etc.).

Applied demo. Despite restrictions on distancing and the number of students allowed in the project room due to COVID-19, all student groups were able to successfully demo their systems over the required tollgates; this required them to proactively collaborate across groups and also apply and combine isolated, theoretical knowledge. One example suggesting that students were engaged and having fun was observed when a student asked if his wife could also build one of the buildings for the cityscape. Some examples of output from research steps, as well as robots and buildings, are shown in Fig. 2, 3, and 4. A video has also been made available that shows some of the students' achievements during the course.[13]

Real World Context. The CAR approach appeared to have allowed for some moderate connection to real world context. All groups included some aspect relating to real challenges and research (COVID-19, SafeSmart). Moreover, students used some current techniques and tools: e.g., the latest versions of ROS (ROS2 Foxy), RPI (4), and Ubuntu (20.04) that were available at the time of the course. In the research steps, students used current tools and techniques such as deep learning with convolutional neural networks (CNN) and Adam optimization [25], AruCo markers [26], dark channel-based dehazing [27], vehicle interconnection metrics [28], model-based mutation testing [29] through MoMut [30]

[13] www.youtube.com/watch?v=qNJry218YMo

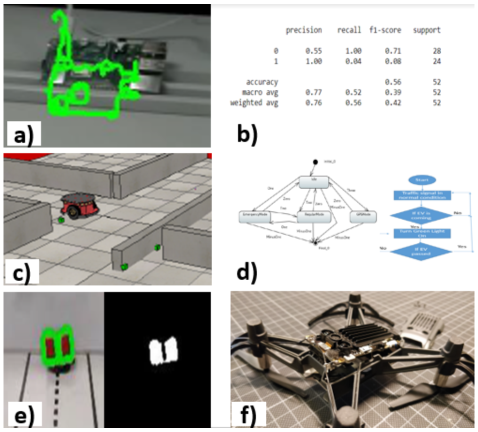

Fig. 2. Examples of research steps: (a) thermal detection, (b) attack detection, (c) fault injection, (d) models (e) EV detection (f) relocating drone camera

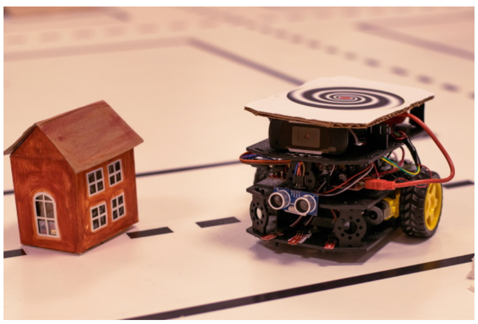

Fig. 3. Wheeled robot

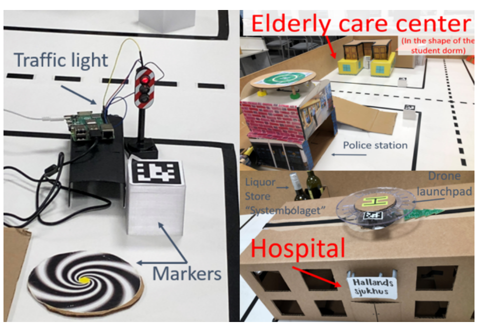

Fig. 4. Buildings

with UML, and Fault Injection-based Automated Testing (FIAT) [31] in conjunction with CoppeliaSim[14].

However, the technical contributions described in the research steps were minor, as is expected from a course setting, especially from a traditional research perspective: it would be difficult to turn any one research step into a conference paper without more work. Another shortcoming was that many students left out typical parts of a research report, such as motivation, related work, data collection details, evaluation, novelty, and future work: Only eleven research steps included at least one reference, eight suggested future work, five described why their topic was of interest, usually in a minimal way, three included an evaluation, and two contained a claim to novelty; no student provided adequate information about the data used, including how many data were obtained and from where.

Moreover, only five students clearly indicated some new results after the main tollgate, and no students explicitly referred to the feedback they had received. Interestingly, two students did not include a description of their research steps in the final report, and one student ”backtracked”, removing material in his final description, mentioning lack of confidence in his ability to develop the idea. We believe the observed variance was mainly due to the open-ended way in which the idea for the research steps was introduced to the students.

B. Student Feedback

Feedback was also obtained from eight students who responded to a standard course evaluation survey that is used in all courses at our university; this response rate was typical (40%). The outcome was that students generally provided positive answers, with an overall rate of 77% (despite a general drop in evaluations of hardware-related courses due to the COVID-19 pandemic; and, compared to a university average of 67%). The students expressed happiness with the course (neutral 25%, agree 38%, and agree completely 38%). Six agreed that the course helped to develop their critical thinking, whereas two were neutral. Some comments about what was best with the course related to CAR: “Everything new and productive”, “The use of new up-to-date technology in general”, and “Researching steps”. As well, this did not mean students had to ignore their other courses: self-reported hours spent on the course were: 16-20 hours (2 students), 21-30 (5, 62%), 31-40 (1), more: none. Thus, all but one student were in the expected range for the course. Furthermore, no comments indicated lack of time to work on other courses that were held in parallel. In conclusion, we believe these results suggested the feasibility of our approach.

C. Benefits to Researchers

What students develop can also be of use to researchers: It provided us with fresh ideas in the area and a way to see what we are doing in a new light, with little investment of time, as well as enabling practical brainstorming and testing of ideas. As one proof of concept, we considered a hypothesis from our previous work on safe braking distances for platoons: during emergency braking, Cooperative adaptive cruise control (CACC) can be used to disseminate information more quickly than ”Autonomous” adaptive cruise control (ACC), thus requiring smaller safe braking distances, and allowing for increases in safety and efficiency [32]. Theory alone might not be sufficient to imagine how such systems compare in the real world; likewise, this hypothesis could be expensive to test with actual vehicles. Therefore, the goal was to test this hypothesis using robots the students had assembled.

Our approach involved setting up a platoon of three robots with nearly identical weight and parts, implementing a proportional controller to allow the robots to follow one another,

[14] www.coppeliarobotics.com

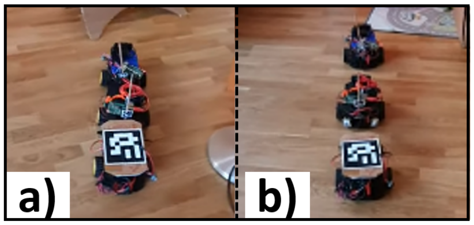

Fig. 5. Example of end state for ACC and CACC: (a) robots were flush against one another, (b) the distance between robots was nearly unchanged.

and simulating emergency braking for two conditions: CACC and ACC. Each case began with the platoon moving with almost constant speed in "normal" mode, of 18 or 38 cm/s, and a steady state distance between robots of about 35 cm. Then, at some moment of time, a key was manually pressed to instruct the leading robot to stop–i.e., to enter "emergency braking" mode–simulating detection of some unpredicted obstacle. The followers were then supposed to stop without rear-end collisions in two separate ways: In the CACC case, the leader, after receiving the command to stop, sent an emergency message (EM) to all of its followers to stop. In the ACC case, followers used only an onboard camera to estimate distance to an AruCo marker placed on the back of the robot in front with an average frequency of 12.4 Hz; braking occurred if the perceived distance fell below 10 cm.

As a result, in the CACC condition, followers stopped almost immediately with the leader, taking between 0.00048 and 0.029 s to receive the braking command; the distance travelled from when the leader was instructed to stop until the moment when all robots had stopped was 1.95 cm. In the ACC condition, the robots stopped just short of colliding, thus moving approximately 35 cm, at 18 cm/s, and even had some rear-end collisions at 38 cm/s. Fig. 5 shows an example of the difference between final resting states of the platoon in the two conditions. The large discrepancy was possibly caused by the simplified recognition approach involving off-the-shelf code and inexpensive cameras. Nonetheless some confirmation was provided that practical scenarios can exist in which wireless communication offers benefits during emergency braking compared with platoons that only use onboard sensors. Moreover, it suggested the general usefulness also of conducting this kind of practical test that can reveal potential problems like sensing errors, which might not be taken into account in purely theoretical work.

IV. Discussion

In summary, the main contribution of the current work lies in reporting on insights gained by exploring how to design master's courses intended to train and engage the next generations of researchers in platooning robots and autonomous vehicles (AVs). More specifically, we started by identifying three unique challenges in AV education related to the emerging nature of the field, restrictions in safety and cost, and high requirements on multidisciplinary knowledge. To address these challenges, we proposed a customized pedagogical approach for AVs called *CAR* that combines *Creativity* theory, *Applied* demo-oriented learning, and *Real* world research context. We identified potential contradictions in the surrounding pedagogical theory and proposed solutions:

- By not considering creativity to be a process that can take different forms (P- versus H-creativity), we risk hindering students from being creative and "throw out the baby with the bath water".
- By not considering that iteratively-refined practical demos can also be used to scaffold theoretical learning, we risk missing out on chances to engage, inspire pride, and gain deeper insight in a safe and inexpensive manner.
- By not considering that research can be done in small steps in regular courses outside of the thesis via tight coupling with projects, we risk losing out on chances for students to feel meaning and a connection to the greater community of researchers in AVs, which might guide them to continue along this path.

Furthermore, we report on applying the approach to a second year master's course with 20 students, which offered chances to be creative by building a demo with 10 small robots using current embedded components and software such as ROS2 and Ubuntu on RPIs, in connection to an ongoing research project and real current problem (SafeSmart and COVID-19). As a result, mutual benefits were observed: The students were able to conduct 20 creative applied research steps in the area of AVs, using some current hardware and software approaches, within the intended timeframes, and expressed satisfaction with the course; also, we described an example of how the students' learning can be used by researchers, in exploring an idea about wireless versus onboard sensors for safe braking.

A. Limitations and Future Work

The results are limited by their exploratory nature, in only considering one kind of robot (AVs) and in including one class of 20 second year master's students, mostly from India and Sweden, with fewer female than male students. Generalizability–in terms of applicability to online learning or other transdisciplinary areas like healthcare robotics or Internet of Things, or scalability to larger class sizes–was not investigated. For example, the ratio of researchers to students was high in our pilot study; although time requirements were low for each researcher, less connection to research could affect the results.

The results are also preliminary for this ongoing work. As is typical for education studies, there was no control group, since the aim was for all students to have the best possible experience. Subjective probing was also kept brief and complemented with objective analysis of the produced reports to avoid acquiescence biases and Hawthorne effects; if such effects could be avoided, further insights could be gained into the feasibility, usefulness, and scalability of the proposed teaching method.

Future work will tackle these limitations and also include applying the obtained insights to improve the DEIS course. For example, one shortcoming was that few students included all of the typical parts of a research report, because we left the tasks open-ended. The next time the course is taught, the lecture content will be complemented by quizzes and templates: The lectures have been streamlined and recorded to allow the classroom to be "flipped" [33] so more time can be spent actively on quizzes and exercises, to encourage increased retention, creativity, and understanding of research. As well, a template will be used for reporting research steps, to provide more scaffolding and help students to remember what basic kinds of ideas should be mentioned; also, the students will be asked to refer to the feedback they receive.

More generally, the insights gained are being incorporated into discussions about our research and education strategies at various levels. At the programme level, it has sparked discussions about accepting shorter journal-length master theses that might make the students' learning more accessible and readable, and at the university level, a movement is ongoing to enhance coupling of education and research.

Thus, the aim is that the reported insights might help to stimulate discussion toward achieving more effective integration of learning experiences that prepare and stimulate students to eventually contribute to research in AVs, and thereby our emerging smart cities and society in general.

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