RAPID: DRL AI: A Career-Driven AI Educational Program in Smart Manufacturing for Underserved High-school Students in the Alabama Black Belt Region

This RAPID project initiated an age-appropriate career-driven AI educational program in smart manufacturing for high-school students. We have developed AI learning modules in the context of smart manufacturing, conducted project-based learning (PBL) experiences based on the AI learning modules, and collected data to investigate the effectiveness of the AI educational program. The outcomes of the project answered the urgent questions of "what to teach" and "how to teach" for high schools to prepare future workforce in smart manufacturing with the necessary AI skills. The AI intervention for high-school students identified the age-appropriate AI learning modules required for smart manufacturing based on the general AI education guidelines and developed innovative PBL-based pedagogy to improve equitable AI learning and promote future manufacturing and STEM careers. The AI educational program also provided valuable information for advancing career-driven, equitable AI learning for K-12 students for other researchers and practitioners.

1. AI learning modules in the context of smart manufacturing

We designed the AI learning modules according to "Five Big Ideas in AI" proposed by Artificial Intelligence for K-12 initiative (AI4K12) [1] and created learning materials and activities in terms of perception, representation and reasoning, learning, natural interaction, and societal impact, in the context of smart manufacturing. We used the Fused Filament Fabrication (FFF) 3D printer as our manufacturing process, for it is the most accessible additive manufacturing process with flexible manufacturability to inspire students' creativity in product design and manufacturing.

Based on the Five Big Ideas in AI, the developed AI learning modules for smart manufacturing include:

1) understand the principles of FFF 3D printing and learn to operate the manufacturing process
2) learn how to design parts with software
3) understand the principles of sensors (i.e., temperature and vibration) and learn to build electronic circuits with sensors
4) learn to collect sensing data and conduct simple analysis with microcontrollers
5) learn to code (in Python) and use machine learning to analyze the data
6) learn generative AI and identify its positive and negative impacts on operations

These AI learning modules are used in instruction and the PBL experience to engage both high-school students and teachers in the AI educational program for smart manufacturing. They are made available on the website: https://auaims.net/service/. Moreover, the AI learning modules can be extended to other manufacturing processes by incorporating process physics, such as biomanufacturing, semiconductor manufacturing, or nanomanufacturing. The procedure of developing AI learning modules for specific application areas from "Five Big Ideas in AI" is also applicable to other industries.

2. Conducted project-based learning (PBL) experience based on the AI learning modules

Based on the developed AI learning modules for smart manufacturing, an innovative PBL experience is developed for students to learn knowledge and practical problem-solving skills and enhance their attitudes and persistence toward STEM careers. The objective of the developed PBL experience is to enable students to build a rocket model with an FFF 3D printer and understand the manufacturing conditions with the help of AI. The activities in PBL include:

(1) self-learning and exploration based on AI learning modules
(2) hands-on, inquiry-based processes to develop solutions
(3) group collaboration and discussion on tasks
(4) sharing the solution and findings
(5) group debate on the societal impacts of AI
(6) guided tours of different labs (e.g., manufacturing labs, virtual reality labs) to see the state-of-the-art technologies

A one-week-long summer camp was structured based on the developed AI learning modules and the PBL activities for high-school students in Alabama. Thirty-three students (about half of them are female) enrolled in a one-week summer camp. They learned 3D printing, engineering design, sensing, microcontrollers, machine learning, and Python coding, successfully built the rocket model with 3D printers, and experienced the future AI-smart manufacturing.

We also developed a three-day professional development session in AI and smart manufacturing for underserved high-school teachers in Alabama to advance inclusive and sustainable teaching. Ten teachers from the underserved high schools in the Alabama Black Belt region were selected to participate in the professional development. Eight of them are African American, and eight of them are female. After the three-day training, the teachers were responsible for facilitating the summer camp activities and developing a lesson plan for continuing the AI educational program at their respective schools to broaden the impacts of the AI education program. The professional development in AI and smart manufacturing for underserved high-school teachers ensured the sustainability of this AI educational intervention.

Teacher participants learned various concepts in AI and smart manufacturing through professional development workshops focused on using Project-Based Learning (PjBL) as a pedagogical strategy to teach the content learned in this NSF-funded project. During the fall semester, teacher participants aligned the content learned in the summer professional development with their existing curriculum and standards and developed a PjBL curriculum for their classroom.

3. Collected data to investigate the effectiveness of the AI educational program

The insights from surveys and data-driven analysis about the effectiveness of the proposed AI educational intervention for underserved high schools provide valuable information for advancing age-appropriate, career-driven, equitable AI learning for K-12 students for other researchers and practitioners.

We used data-driven methodologies to investigate the effectiveness of the developed AI educational intervention in improving students' AI learning and their interest in further education and career in smart manufacturing, and in meeting teachers' needs for age-appropriate career-oriented AI education for underserved high schools. Specifically, a mixed-method longitudinal design is used to collect data and examine the progress of project participants throughout the teacher professional training workshop and student summer camp.

Teacher Professional Development Workshop

Participants

A total of 10 middle and high school teachers participated in the summer professional development workshop and student summer camp. Eight (80.0%) were female, and the majority of them (80.0%) were Black. Eight teachers (80.0%) received a master's degree or above, while others (10.0%) received a bachelor's degree and one specialist (10.0%). They had a wide range of teaching experiences from 3 to 33 years (*M*=19.22, *SD*=8.86). For the 2024-2025 academic year, four teachers (40.0%) will teach in high school, three teachers will teach across middle to high schools (30.0%), and three of them (30.0%) will teach middle school only. Four teachers (40.0%) taught a discipline specialized in Career Technical Education, and the rest of them were math (10.0%) or science teachers (50.0%). Out of 10 teachers, 9 teachers participated in both pre- and post-survey.

Measures

A 19-item knowledge scale was developed by the project team based on the summer camp content to assess both teachers' and students' knowledge gains. Teachers and students selected all applicable correct answers from multiple-choice options, and each correct selection was recorded. For questions with multiple correct answers, each option was treated as a separate item, and the accuracy rate for selecting correct answers was calculated.

Additionally, teachers also completed a questionnaire including Patterns of Adaptive Learning Scales (PALS, Teacher Version)[2] to measure teachers' perceptions of the goal structure in the school, their goal-related instruction approaches, and personal teaching self-efficacy, computer and programming self-efficacy scales. The internal consistency reliability coefficient for the teacher surveys was between .63 to .95.

Procedures

The project team developed professional development materials focused on AI in Smart Manufacturing, covering topics such as 3D printing, CAD and Solid Works, Python and Coding, ChatGPT, and Generative AI. Teachers completed a pre-survey at the beginning of the 3-day summer professional development workshop and the post-survey at the end. A focus group interview was also conducted at the end of the summer professional development workshop. Paired samples t-tests were conducted to evaluate the changes in students' knowledge, attitudes, motivation, and self-efficacy. Focus group interview was recorded, transcribed, and analyzed using a content analysis approach.

Results

Survey results. Pair samples t-test results indicated that teachers' perception of school structure focusing on students' performance significantly reduced with large effect size, *t*(7)=-2.50, *p*=.02, Cohen's *d*=-0.88, while their computer and programming self-efficacy significantly improved with large effect size, *t*(7)=2.35, *p*=.03, Cohen’s *d*=0.83; *t*(7)=3.90, *p*=003, Cohen’s *d*=1.38; respectively (Table 1).

Table 1. Teacher Survey Pre-Post Comparison Results

	Pre	Post				
Scales	*M* (*SD*)	*M* (*SD*)	*t*	*df*	*p*	Cohen's *d*
Summer Academy Knowledge	73.10% (0.22%)	71.21% (0.30%)	-0.15	9	.44	-0.05
PALS						
Mastery Structure	4.03 (0.54)	4.09 (0.73)	0.26	7	.40	0.09
Performance Structure	3.43 (0.74)	3.25 (0.72)	-2.50	7	.02*	-0.88
Mastery Instruction	4.13 (0.35)	4.14 (0.48)	0.19	7	.43	0.07
Performance Instruction	3.63 (0.51)	3.56 (0.58)	-0.53	7	.31	-0.19
Teaching Self-Efficacy	3.98 (0.66)	3.84 (0.65)	-0.76	7	.24	-0.27
Computer Self-Efficacy	2.30 (1.05)	3.10 (1.10)	2.35	7	.03*	0.83
Programming Self-Efficacy	1.48 (0.47)	2.04 (0.47)	3.90	7	.003**	1.38

$^{*}p < .05$ ** $p <.01$, $^{***} p <.001$

Focus group results

1. Technology integration in school curricula
   Teachers emphasized the importance of introducing students to updated technology at an early age and highlighted the need to modify school curricula to facilitate learning. They valued hands-on, tangible activities the project team designed that allow students to apply their knowledge immediately and receive real-time feedback from instructors.
2. Incorporating lesson plans for career readiness
   Teachers shared their plans to introduce coding to students and to use tools like 3D printers to create effective teaching aids. They discussed integrating lesson plans focused on career development and workforce readiness into their teaching practices, preparing students for future career opportunities.
3. Enhancing student engagement in classrooms
   Teachers identified the need for engaging in activities to maintain students' attention during lectures, especially for younger students. One of the teachers suggested incorporating interactive methods, such as note-taking and using microphones to keep students engaged. Teachers also emphasized the importance of adapting lesson plans to accommodate students of varying abilities and incorporating more hands-on activities to enhance understanding and retention.
4. Challenges of implementation
   Teachers discussed several challenges, such as engaging disinterested students and managing large class sizes. They stressed the need to limit class sizes to ensure adequate attention and engagement. Additionally, they highlighted the necessity of support from school administrators and sufficient funding for resources like 3D printing materials and computers.
5. Positive impact of the summer professional development workshop and student summer camp
   Teachers expressed overwhelmingly positive experiences with the program, noting that it provided students with valuable skills, career exposure, and improved behavior and engagement. They emphasized the importance of continuously updating their own technological skills and fostering collaborations with local universities and community colleges. Teachers recommended that the summer program continue and expand to include different levels of professional development opportunities.

Student Summer Camp

Participants

A total of 33 students completed the pre-survey. Of those students, 21 (63.6%) were males and 11 (33.3%) were females. The students ranged from 7th to 12th grade, with the largest group in 12th grade (n=11, 36.4%). Their age ranged from 12-17 years old, M=15.27, SD=1.72. There were 13 (39.4%) White students, 10 (30.3%) Asian students, and seven (21.2%) black students. The majority (n=30, 90.9%) reported "definitely yes" about planning to attend college. Regarding educational aspirations, 12 students (36.4%) aimed to achieve a bachelor's degree, 10 (30.3%) planned to obtain a master's degree, four (12.1%) intended to pursue a doctorate, and seven (21.2%) were unsure. When asked about their technology experience, 19 students (57.6%) rated themselves as average, eight (24.2%) as advanced, and six (18.2%) as beginners.

Measures

The 19-item knowledge scale developed by the project team was also used to assess students' knowledge gains.

Additional measures included subscales from the Motivational Strategies and Learning Questionnaire (MSLQ)[3], intrinsic goal orientation, extrinsic goal orientation, peer learning, and critical thinking, and selected subscales from the Student Attitudes toward Science, Technology, Engineering, and Math (S-STEM)[4], engineering and 21st-century skills, programming self-efficacy, and STEM career interest. The internal consistency reliability coefficient for the student surveys ranged from .57 to .90 for the pre-survey and from .52 to .91 for the post-survey.

Procedures

The project team developed learning materials focused on AI in Smart Manufacturing, covering topics such as 3D printing, CAD and Solid Works, Python and Coding, ChatGPT, and Generative AI. Students completed a pre-survey at the beginning of the 5-day summer camp and the post-survey at the end. Paired samples t-tests were conducted to evaluate the changes in students' knowledge, attitudes, motivation, and self-efficacy.

Results

Results indicated that students' levels of intrinsic and extrinsic goal orientation, STEM career interests, and programming self-efficacy were significantly improved with a large effect size, $t(25)=9.01$, $p<.001$, Cohen’s d=1.77; $t(25)=8.34$, $p<.001$, Cohen’s d=1.64; $t(25)=2.15$, $p=.04$, Cohen’s d=0.82; $t(25)=4.24$, $p<.001$, Cohen's d=1.27, respectively (Table 2).

Table 2. Student Survey Pre-Post Comparison Results

	Pre	Post				
Scales	*M* (*SD*)	*M* (*SD*)	*t*	*df*	*p*	Cohen's *d*
Summer Academy Knowledge	72.5% (25.4%)	71.1% (30.4%)	-0.19	37	.853	-0.42
MSLQ						
Intrinsic Goal	3.73 (0.75)	5.00 (0.85)	9.01	25	<.001***	1.77
Extrinsic Goal	3.30 (0.87)	4.50 (1.08)	8.34	25	<.001***	1.64
Peer Learning	3.27 (1.11)	3.65 (1.01)	1.96	25	.057	0.39
Critical Thinking	3.38 (0.90)	3.51 (0.96)	0.83	25	.416	0.16
S-STEM						
Engineering Attitude	3.98 (0.73)	4.06 (0.68)	0.83	25	.412	0.55
21st Century Skills	4.12 (0.62)	4.22 (0.62)	1.51	25	.072	0.69
STEM Career Interest	4.36 (0.53)	4.47 (0.55)	2.15	25	.041*	0.82
Programming	2.19 (0.56)	2.50 (0.55)	4.24	25	<.001***	1.27
Tech Experience	1.96 (0.72)	1.85 (0.68)	-1.36	25	.185	-0.43

**p* < .05 ** *p* <.01, *** *p* <.001

References

1. *The Artificial Intelligence (AI) for K-12 initiative (AI4K12)*. Available from: https://ai4k12.org/.

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