6. An Industrial Arts Class That Works: Manufacturing in the Vocational Lab

By the close of winter semester, Mr. Benson’s mechanical drawing class of fourteen students had divided into groups of two to three students, forming semiautonomous manufacturing teams, each focused on a different aspect of a single manufacturing project. In the previous semester, they had completed instruction and extensive practice in mechanical drafting, design, and mathematics, correlated to the vocational material, and now they applied these skills to a manufacturing project. The entire second semester involved the challenging, whole-class project of manufacturing a model toy tanker truck from raw materials (wood, plastic, metal) to prototype and then “mass” producing thirteen toy trucks.

Again, we begin with a vignette based on field notes to convey a sense of this classroom on a typical day:

Mr. Benson dismisses the architectural class in the adjacent room, just as members of the manufacturing teams stream into their lab. Beginning early is the recent “rule” for the thirteen boys and solo girl working on the manufacturing project.

As soon as Mr. Benson frees himself from a lingering architecture student, Trent, from the woodworking team, flags him down to discuss the “undercarriage” of the tanker prototype now under production. Anticipation over completion of the prototype provides the impetus for the manufacturing “teams’” early appearance and particularly Trent’s (a boy with well-honed skills at loafing) newfound enthusiasm with the project. Another student walks by carrying boards. There is activity all around as pairs or triplets of students carry out tasks. Mr. Benson moves about between the computer room, wood shop, and drafting lab, where he stops to consult and to pose and answer questions.

Ann, seated at a keyboard, and her partner Carl work at the CNC milling machine from the design team’s drawing of a ladder for the side of the truck cab. They are in command mode in the CNC programming language and do a demonstration run of their program: it draws the pattern that they have programmed on the screen. The result is not perfect—only the outline of the ladder comes out—and they begin reprogramming.

The design team, waiting for the drafters to finish a drawing, discusses another student who “got admitted to UC Berkeley but is going to UCLA.” The conversation continues about how hard it is to get into Berkeley and how this guy is blowing them off to go to UCLA. Ann and Carl join the conversation with some interest and then get back to work as the drafters join the group and turn the subject to Kung Fu,
knives, fighting, and proper ways to kill things. Mr. Benson slows down the conversation with a glance in their direction.

Back in the wood shop, the two-member woodworking team engages in a discussion about the angle cut that needs to be made on the roof piece of the truck. They compare the piece to the drawings of the truck, and then place it directly on the piece of drafting paper to see how it lines up.

Mr. Benson approaches the design and drafting teams with a reminder that they need to complete the “3-D” views or produce a “pictorial” of each part of the cab. Mr. Benson points out that the woodworkers have almost completed the front piece, so they should hurry with their design and drawings because the woodworkers will want to start prototyping the tanker body. With repeated consultations between themselves over details in the design, these teams are well on their way to completing the preparation needed.

Mr. Benson whistles for cleanup just before the bell rings for lunchtime. He returns to the computer room to help Ann write out the CNC file.

With all the labs empty, Mr. Benson excitedly works on his kiosk for the upcoming grant fair being sponsored by a local firm. Mr. Benson works especially hard since he will compete with nearly 400 schools, which, like his, are seeking grants to help their special projects.

**Instructional Goals**

The instructional goals we discuss below were not explicitly taught or identified as teacher goals. Rather, we observed that the classroom design and assignments required students to learn and apply generic problem-solving skills and work attitudes, cooperative skills, and domain-specific skills.

**Complex Reasoning Skills**

This class provided many opportunities for students to exercise complex reasoning skills. Mr. Benson assigned the class to build thirteen tanker truck models and he provided rough drawings completed by students in the previous class. Students were left to specify the designs and identify and solve the engineering and manufacturing problems inherent in their decisions. They defined, planned, and solved problems largely on their own, with occasional tips or advice on request from Mr. Benson.

The following example involved a group of three boys who were assigned to design the carriage for the truck. The interaction began with Mr. Benson defining a problem for the group, providing some materials, then leaving. In his absence they proceeded through problem analysis and then continued to work through the problem.
EXAMPLE: Mr. Benson asks them: “One other question: how to fasten this (pointing at cradle) to the base?” [Mr. Benson does initial problem recognition for the team.]

One student suggests using screws. Jered wants to know what the screws look like. [Generation and assessment of solution path.]

Benson brings Jered drywall screws of various lengths and then leaves. Jered suggests using two screws for holding the cradle onto the base. [Generation of alternative solution path.]

Randy comes up with the idea of using a single screw to go up through the base, the cradle, and then into the plastic pipe to hold the whole thing together. Other team members express approval of Randy’s solution. [Generation of alternative solution path and evaluation.]

Benson walks by while making walking rounds, and Randy tells him about the idea of using one screw. Benson thinks about this. He appears to have a problem with the plan and says: “Stop and think what this presents. . . .” Benson thinks some more and suddenly says, “Beautiful. That is a beautiful move. It saves materials, but what do you have to do?” [Evaluation and reflection.]

Jered: “Make sure the holes line up.” [Recognition of problem.]

Having come though a full cycle of problem solving, progress was made. Progress brought opportunity to solve additional problems. With each successive problem solved during the design cycle, students were faced with contingencies from their previous solutions.

EXAMPLE: As the design group talks over the design, Carl notices that the measurement they are using for their cradle design is actually the diameter of the cap and not the pipe. They had determined earlier that the pipe’s diameter was the measurement they needed. Randy and Jered agree that they are making an error. Carl changes the diameter of the design and proceeds to finish the drawing. [Reflection, problem recognition, solution generation, and repair.]

**Work-Related Attitudes**

Learning in the “manufacturing” classroom was similar to working on a shop floor. Students used the power tools on their own, planned their own work, and communicated progress and delays among teams, all in the service of completing the final product. Mr. Benson monitored students and their activities as he
roamed the three-suite classroom, but self-managing student-teams were generally on their own.

Because this was an active work-laboratory, students faced realistic workplace parameters, such as needing to proceed despite a key team member’s absence or forced downtime when others were behind schedule. These workplace parameters provided students with opportunities to develop useful work-related attitudes.

EXAMPLE: Student says that the class has generally helped him prepare for work because he understands the process of design, and if he goes into a job he won’t be surprised or “get my head bit off.”

Make Decisions. Mr. Benson taught students to make and evaluate their own decisions.

EXAMPLE: Concerned, Randy questions Mr. Benson to learn if he suggested the “wrong” solution, or if he was “supposed to” think of some different solution. Mr. Benson responds that “there’s no question of ‘supposed to’ as long as you have thought out all questions.” Mr. Benson leaves, and the design team appears to feel positive about their design and Randy’s solution.

In the above example, Mr. Benson surrendered his role in evaluating students’ decisions. Instead he provided a guideline for evaluating one’s own decisions.

Take Responsibility for Actions. About three of the fourteen students have reputations as troublemakers, loafers, or “yahoos.” They presented a special challenge to Mr. Benson in teaching responsibility for one’s actions. Mr. Benson insisted that students be responsible for their team’s assignments.

EXAMPLE: Trent, a student who recently overcame a poor attitude and general apathy, is showing some anxiety that his team partner is absent and says that he “sure hopes that Arthur shows up today.” Mr. Benson replies that “if Arthur’s not here, you’ll have to carry the ball.”

EXAMPLE: Student is working through a difficult fabrication problem for most of the period. Asked by the fieldworker when he plans to check in with Mr. Benson, he says that he doesn’t have to consult with him.

Another aspect of being responsible was associated with personal behavior. Even though Mr. Benson expected students to carry out their work, he did not overmonitor their activities.

EXAMPLE: There is activity all around as pairs and triplets of students carry out tasks. I (fieldworker) hear the tablesaw start in
the woodshop room and am surprised to see Mr. Benson standing
calmly in the CAD lab. He is undisturbed by the kids using the
saw in the other room and doesn’t seem to notice.

Cooperative Skills

In keeping with his practice of having students take responsibility for making
and evaluating their own decisions, Mr. Benson taught cooperative work teams
to distribute evaluation responsibility among the group. By doing so, he
clarified his expectations for teamwork.

EXAMPLE: Mr. Benson says to other members of the design group:
“You guys have to police each other. You have to check each other.
That’s part of working on a design team.”

Mr. Benson wanted students to settle their own differences of opinion. He stated
that resolution was needed, but he did not explain how they might resolve their
differences. Unlike Ms. Adams (cf. Stasz et al., 1990), he did not teach
procedures or have students practice consensus exercises:

EXAMPLE: Carl asks Mr. Benson if they should make the outside
of the cradle into an angle, or make it straight. Randy interjects that
he prefers a different design. Mr. Benson says: “Okay, somewhere
along the line somebody gives in. You guys have to work with it.”

In the above example, Mr. Benson put dispute resolution in the hands of two
students who were having a difference of opinion over a design decision.

Domain-Specific Skills

As in the electronics class, Mr. Benson strove to integrate multiple domains in
manufacturing. Manufacturing the model truck required students to integrate
domain-specific skills. They routinely used math and drafting for designing,
Woodworking skills were needed for the tooling and fabrication task. Mr.
Benson also taught students to use computer-aided design (CAD) and the
computerized numerical control (CNC) mill.

Classroom Design

The manufacturing classroom had a very comfortable, open feel to it. Students
circulated, mixing work and some socializing. It had the look and feel of a
manufacturing “shop floor” where design prototype teams work. There is no
sense of urgent rush, nor any real sense of just goofing off. Students appeared to
like and trust Mr. Benson. They readily helped each other. This lent a feeling of comfort to the class—students didn’t seem to mind learning and working here. Students generally knew their tasks and worked with their groups to accomplish them. Mr. Benson circulated, monitoring and making himself available as a resource.

Teacher Roles

Mr. Benson moved flexibly between the role of “master” for student “apprentices” and the role of “general manager” of the manufacturing classroom. The master-apprentice approach proved useful when he concentrated on teaching and modeling problem solving to students with limited skills. He was an able “master” who took every opportunity to model his thinking process when he perceived that a team might be floundering. During such moments, he attempted to instill appreciation for the integrated domain.

More frequently he took the role similar to that of a general manager in a small manufacturing plant. In this role, he was far less directive with students. He served as technical consultant, questioner, and devil’s advocate. He was able to do this because his teaching assistant, a second-year student, supervised “the floor.”

Mr. Benson assumes the traditional role of classroom disciplinarian when needed. As with the electronics class, Mr. Benson was tolerant of students’ socializing and joking, and even a small degree of “goldbricking.” He was, however, actively confrontational with students who fought with other students or placed others in danger.

EXAMPLE: Jed returns to class to “beg forgiveness” from Mr. Benson. Jed had fought with Ed earlier in the period because “Ed thought I threw a bee on him,” and both were thrown out of class. Both students claimed to be sorry. Mr. Benson fires back that what Jed and Ed did was wrong and dangerous and that they were “totally unconcerned with anyone else’s safety.” After a few more exchanges, Jed asks, “Am I still able to be in the class?” Mr. Benson replies, “Yes, but if you screw up one more time you are out.”

Keeping with his approach in the electronics class, Mr. Benson did not hold a grudge once students made an effort in class.

EXAMPLE: The day following Jed and Ed’s fight, Ed puts in a full period of work on the drawing team. Toward the close of the period, Ed shows Mr. Benson the red spot on his hand and says, “Bee sting.” Mr. Benson accepts the joke as he replies good
naturedly, “Good! You’ve taken the life of that bee. You’ll have to carry that burden to the grave.”

In keeping with his philosophy that schools should avoid “throwing away students,” Mr. Benson also played “counselor” to his problem students. One student came into the class with attendance problems. Over time Mr. Benson noticed a “strangeness” in his behavior and had hints that the student’s family embraced social beliefs about racial superiority. The student’s attitude typically swung between general apathy and open disapproval toward learning skills or cooperating with team members. Rather than threatening the student with a failing grade or dismissal, Mr. Benson chose to counsel him:

EXAMPLE: After several weeks of observing Henry’s “strangeness,” Mr. Benson decided to talk with him one-to-one about “the need to stop the [strange behavior] and realize he’s human. Human people need to think about where they are going and develop skills so they can contribute to the world and their own family.” After several of these discussions, Henry began to drop his strangeness. When the fabrication team ran into problems, Henry applied himself and came through for the group by designing a tool for fabricating the cab section.

**Situated Learning**

As in the electronics class, Mr. Benson situated learning in the manufacturing class in authentic tasks. During the first semester these were mechanical drafting and design activities that taught basic domain skills. In the second semester, he situated learning in the context of a classwide manufacturing project. Manufacturing required students to create production designs and make a prototype. The project also required students to produce jigs and tools to build the toy trucks, using both standard and computer-controlled tools.

As this description suggests, Mr. Benson sequenced learning tasks. For example, during the first semester he taught drafting skills and corrected student drawings and math deficiencies. Students executed a series of steadily more difficult perspective drawings of three-dimensional solid figures. With these “basic” domain skills introduced and mastered by the majority of students, he moved into integrated manufacturing during the second semester.

**Culture of Practice**

Students were engaged in a “manufacturing culture.” The work in the second semester was explicitly team based. Most students worked as members of the
production team. Since teams carried out different parts of the process, each was responsible for keeping the work moving to the next team in the assembly line.

Mr. Benson treated the project as business and held student teams accountable for progress. Students routinely communicated their progress or unexpected delays to others. Students who slowed down the project, because of their "bad behavior," were not tolerated by most. Typically, "bad behavior" involved horseplay or excessive joking that slowed others’ progress. However, if the reason for the slowdown was a matter of someone lacking the skill or experience to complete the task, other students readily came to their assistance.

**Motivation**

As with the electronics class, Mr. Benson echoed his judgment that the best motivator is to prepare and support students for a task. This judgment is reflected in his sequenced instruction and in his supportive roles as teacher.

Mr. Benson also used technology as a motivating component of classroom design. For instance, he used computers to motivate and engage students: “Kids love them. It’s a way to get kids involved with the subject matter.”

The interdependency of teams in achieving the common goal appeared to deflect students from competing with each other. Moreover, because students received individual grades, rather than team or project grades, students focused on their personal contribution to their team’s task.

**Cooperation**

In this class Mr. Benson also relied strongly on cooperation among students to foster engagement and motivation: Unlike in the electronics class, students in the manufacturing class were all engaged in a single common goal, like workers in a small firm. There was a strong feeling that each work team had to work with the other teams to “get the project done”:

EXAMPLE: Ann says, “But you can’t do that [mess around] because the groups depend on each other. One group has to wait for another [in the sequential manufacturing process].”

EXAMPLE: Trent explains his effort: “The groups have to be in sync. You check your group’s progress with other groups. You find you can get ahead or fall behind.” Randy elaborates further that “when I make a modification to a drawing, I have to tell everyone.”
Mr. Benson promoted cooperation among his students, and they frequently sought and provided help to one another. Students moved freely between drafting tables and classrooms, asking and helping.

There was not only a strong cooperative element in the design of the project, but Mr. Benson also placed the responsibility for negotiating the cooperation onto students themselves. He did not manage their groups, they managed themselves. Overall, students appeared to thrive on the high degree of responsibility that interdependence implies. Activity and involvement with meaningful tasks apparently contributed to this positive work environment. However, one student indicated the fragility of this arrangement:

EXAMPLE: Bob says, “If you like the work, you do it.” Randy agrees, “Yeah. If there is a ‘work ethic’ in the classroom, then you want to work. If there is messing around going on, then you want to do that too.”

Teaching Techniques

Mr. Benson employed a range of teaching techniques to teach generic and domain-specific skills. We did not observe the full range of techniques that we observed in his electronics classroom, perhaps because of our shorter (five days) observation period in this classroom. However, the style of instruction in both classes was similar. Mr. Benson used modeling, coaching, and several other techniques outlined in the previous section.

In keeping with the manufacturing task, he did not lecture, but rather provided one-to-one instruction to individuals and to teams. Typically he monitored progress by circulating through the three lab rooms, stopping occasionally to critique and advise teams or to assign a task. Conversation between the teacher and students was relaxed and easy:

EXAMPLE: Mr. Benson stops at Bob’s desk and asks what he’s doing. Bob looks like he’s out of work, so Mr. Benson gives him the task of working on the hitch drawings, and they discuss how to position the screw holes in the drawings. Mr. Benson then moves to the next desk and assembles the pieces of the prototype, talking to the group of students as he goes: “We’ll have to figure out how to glue this bugger together.” Trent: “Glue the whole thing . . .” (laughing with Mr. Benson and other students). Mr. Benson: “We need to make one. That’s why we’re building the prototype, so we can figure out how to assemble it.” He proceeds to talk through the gluing process with students adding their ideas.
**Modeling**

In keeping with his attempt to have students take responsibility, Mr. Benson offered problem-solving heuristics to students:

EXAMPLE: Mr. Benson scans Peter’s drawing and tells him that “you want to bring the dimensions together in one place on the paper, as much as possible.” After discussing another matter on the drawing, he asks, “Why should you group the dimensions together?” When Peter fails to answer, Mr. Benson supplies the answer: “So you don’t have to look all over the drawing to find the measurements you want.”

Here Mr. Benson models the kind of thinking (general rules and their rationale) that underlies the expert practitioner’s actions.

**Articulation**

While evaluating students’ work, Mr. Benson asked specific questions and requested that students attempt to solve specific problems. This permitted students to articulate or demonstrate their knowledge, reasoning, and problem solving:

EXAMPLE: Then Mr. Benson points out redundant information on the drawing and waits for Peter to decide which to erase and which to keep. Peter decides to keep the best placed one, and Mr. Benson compliments him on his choice.

**Scaffolding and Fading**

Mr. Benson provided physical and verbal supports for students. For example, with his guidance a team of students produced a series of drawings of the assembly process. These drawings provided instructions to other teams on how to proceed. Likewise, Mr. Benson provided detailed and clear support when students seemed to lack a full understanding of some procedure or process.

EXAMPLE: A student is trying to figure out the radius of the circle that forms the wheel well of the toy model. The radius is not recorded on the drawing and he can’t remember what circle his team used. Mr. Benson asks him if he remembers how to find the center of a circle using a compass. The student does not remember. Mr. Benson reteaches the method of drawing two secants, constructing perpendicular lines to the secants, using a compass and ruler, and then finding where the lines cross. The student uses this method on his problem, with Mr. Benson providing just enough assistance to accomplish the task.
Student Perceptions and Accomplishments

The manufacturing students had a diverse set of reasons for attending the class. The majority needed the math credit that came with it. Three advanced students saw it as preparation for engineering careers. Others thought they were signing up for an easy class. A few students headed toward vocational careers (e.g., plumbing or tooling) thought that they would learn generally useful skills that would transfer to their trade. Finally, several had no goals for the class and were placed by a counselor. Like the electronics students, the manufacturing students eventually recognized the class was a way to receive individual instruction from a knowledgeable teacher.

During focus groups and survey, we learned what students accomplished as a result of the class, including thinking through complex problems, planning skills, and cooperative skills, as we discuss below.

Complex Reasoning Skills

Students expressed an appreciation for and demonstrated new ability to think through complex problems. Mr. Benson observed that even the “toughest guy” beamed over the thirteen trucks as they rolled off the line. Students had “wide-eyed appreciation.” He reflected that this class was one of his more successful groups because they really became “hooked on thinking” when they could see the results of their efforts.

EXAMPLE: Carl says that he learned a “way to think”—he learned that he could learn to see objects from many different views and calls this “spatial visualization.” When asked to compare this class with others, Carl replies, “No comparison. This class is different. It is using your brain instead of memorizing.”

EXAMPLE: David says the course has changed the way that he looks at the world. Until he took the course he had no idea how complex things are and how much thought, design, and work goes into things. He points to the paper cutter as an example and says that there must be a hundred drawings of the parts of a simple tool.

On the survey nearly all students (38 percent agree, 48 percent strongly agree) indicated that “it is important to learn to figure things out for yourself.”

Planning Is a Useful Work-Related Skill

Students also discussed planning as an important work-related skill. Planning, of course, is also part of problem “analysis,” e.g., determining a sequence of steps
to take. Students had learned to plan in the process of working in teams and interdependently accomplishing the final project with other teams. They learned planning in a “situated” fashion and understood planning in terms of accomplishing work.

EXAMPLE: Arthur says, “I learned to work things out in my head, to think ahead when you’re doing a job.”

EXAMPLE: Trent says that in mass production “there’s a lot of planning. You have to think ahead. It’s fun.” He had done odd jobs for money recently, and had applied “think about what you do before you do it,” which he learned in the class.

In the above examples, the students described learning to use mental models. They also acknowledged the sequential nature of problem solving. Finally, they implied that the challenge was fun.

**Value of Cooperation**

Late in the semester, students reflected on the value of group work over individual work:

Trent: “The switch from individual to group work has helped.” Other students agree that the class is more interesting now that the manufacturing groups are set up because Mr. Benson provides more individual attention and the team assignments are more interesting and challenging. Randy agrees: “In the beginning of the year we drafted out of a book. It was busy work.” Bob adds: “But, now, the class works.”

**School Context**

*Access to Knowledge*

Students had the opportunity to learn across several domains in this classroom. Having the class span over two semesters permitted Mr. Benson to concentrate on teaching drafting and math “basics.” Math was correlated to mechanical drafting. Students also employed woodworking skills learned in previous vocational classes to build tools and fabricate parts. Moreover, the final project required that students work within these domains in an integrated fashion.

Resources were important to learning. Mr. Benson had been able to enrich his students’ opportunities by upgrading equipment and designing a class around the manufacturing project. The three-classroom/lab suite and the equipment were shared between electronics, the mechanical drawing/manufacturing class,
and an architectural drawing class. Because Mr. Benson was the only teacher for these subjects, he had full discretion to use these resources according to his purposes. However, he was the only teacher because the school’s curricular focus was college preparation, not vocational education.

**Press for Achievement**

The school and district expected and valued high achievement, but the focus was on the college-prep curriculum. As a result, students in this classroom felt little press for achievement from the outside. Students were placed in the class for different reasons. Those with poor math grades were placed to pick up the math credit. Those with “known discipline problems” were shunted from more academic classes to “practical” vocational classes. A few college-prep students with interest in technology and engineering elected to attend. The class, then, was an elective for some and for others it proxied as a required math class. (Although the school tracks students by “ability group,” Mr. Benson made no effort to maintain grouping by ability in his classroom.)

**Professional Teaching Conditions**

Administrators gave Mr. Benson high marks on teaching and praised his efforts to challenge his students, who are generally perceived as the less-able cohort of students. His broad training and experience were recognized and valued.\(^1\) Although the school provides very little in the way of staff development, he was able to attend professional meetings and workshops several times yearly.

---

\(^1\)As indicated in the preceding section, Mr. Benson has no industry experience, but he works on a hobby level on all aspects of industrial arts. He is certified in math, physics, and vocational education. He is also involved in a statewide consortium on teaching manufacturing in secondary and postsecondary schools. He is an avid learner, having earned an MS in industrial technology and an MFA in furniture design.