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Mixing with Intelligent Mixing Systems: Evolving Practices and Lessons from Computer Assisted Design

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ABSTRACT

Intelligent Mixing Systems (IMS) are being integrated into mixing workflows, however, there is little discussion around how these technologies are impacting mixing practices. This study explores the possibilities and pitfalls of IMS, by comparing to the use of Computer Assisted Design (CAD) tools in the wider design context. The aim of this paper is to take advice from the field of CAD about the potential benefits and known issues of computer-assistance in creative work, thereby allowing audio engineers to take more informed decisions regarding the use of IMS within their workflows.

1 Intro

Technologies that assist and automate parts or the entirety of the mixing process, Intelligent Mixing Systems (IMS), are rapidly becoming part of music mixing workflows. Some IMS are intended to fully automate mixing, but many systems are designed to *assist* mixers. These assistive technologies are of primary interest, within this discussion. So far, there has been little formal discourse around the impact of IMS on mixing practices. Mixing is not the first creative practice to adopt assistive and intelligent technologies. Lessons about computational assistance can be drawn from a number of different, yet related fields, including design and Computer Assisted Design (CAD). Mixing and design are comparable activities in that in most professional contexts, both are creative yet goal-directed, constrained by client and commercial requirements. From this comparison of mixing with IMS to designing with CAD, we stand to gain better understanding of the benefits and challenges of utilising computational assistance.

The field of design has produced a body of literature that is instrumental in informing the development of CAD technologies, and has guided the evolution of design practices to embrace CAD's potential. This research has also contributed to the design pedagogy that prepares future designers to utilise computational assistance in a professional practice. These same possibilities exist in mixing. To optimise the benefits of IMS capabilities, we can shape technology design, professional practice and pedagogy concurrently.

2 Rules, Standards and Creative Practices

While there exist best practices, common workflows, and conventions [1], there are no standardised approaches to mixing [2, 3]. Individual mixer engineers differ in their approaches, habits, styles and the application of technology, adding individuality to the results. In mixing, as in design, individuals are hired for their ability to meet professional norms, standards, and to add their own unique qualities to the mix. According to Dorst, the designer "has the privilege and the problem of working in both an *objective* and *subjective* mode." They enjoy a degree of *freedom* to exercise their *personal style* yet within the constraints imposed by "the assignment that they were given" [4, p. 141]. *Good* or viable solutions in design, and in mixing, balance and integrate the subjective and objective perspectives. In design, Dorst refers to this behaviour as "reflective" [4]. The balancing of perspectives is not arbitrary. There are reasons and rules that emerge from common practices and conventions, and these tend to govern what constitutes a *good* design or a *good* mix. Designers and mixers learn these rules formally, and through practical experience.

Not every mix or design decision is guided by rules. In particular, it can be difficult to formulate rules for the idiosyncracies each mixer brings to the process. Such things are evaluated subjectively. Rules pertaining to the more objective qualities may be twisted or broken to create new variations. Moreover, not all rules are suitable and/or applicable in every context. "Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution *spaces* - problem space and solution space." [4, p. 142] Rules are applied at different times and in different orders. As the engineer explores the mixing space, while considering the creative possibilities, rules may change and be refined over time [5]. This flexibility, managed by the mixer or designer, contributes to the character of the project.

CAD assists by facilitating explorations of the problem space, through visualising, simulating, testing potential solutions and with the application of rules. To this end, CAD manipulable design into parameterized attributes, it proceduralizes designing so that functionality enables designers to enact common rules. Most forms of IMS are similarly built around common mixing rules. Currently, most available IMS systems propose to assist with technical aspects of mixing only [6], that is, mixing tasks that are plausibly evaluated with objective measures. IMS assists with, for example, dynamic range compression [7], a task that can most readily be defined, modelled or evaluated using objective measures. Effective assistive computational technology defines rules, parameterizes and proceduralizes sufficiently to facilitate *viable* outcomes. The technology produces mixes that seem as though an experienced mixer would make. However, it is not so clear what happens when these rule-based capacities are integrated into a workflow, and how they will influences the mixer /designer's subjective perspective.

3 Intelligent Mixing Systems

There are a number of approaches for developing an IMS', with a variety of scopes. Moffat and Sandler propose that IMS need to be designed with the intended style of human interaction considered [8]. They suggest four categories of human interaction with an IMS that span a range covering an *insightive* system, which is designed to inform and provide the user with easier access to information regarding the musical content they are mixing, through to a *fully automatic* approach, where all control over the music mixing is relinquished to the IMS. Each of these levels of control can have benefits.

Intelligent references the ability for a system to perceive, interpret and act within a given context. As such, there is an understanding (at least on part of system designers) that IMS may have to demonstrate intelligence about a musical context to apply to processing or some other *rule* about mixing audio [8]. These systems range from purely deterministic systems based on signal analysis [9], optimisation approaches where constraints are defined for the solutions sought [10] and to a fully automated machine learning approaches [11].

A number of studies have attempted to identify, define and apply mixing rules [12, 13]. However, all of these systems suffer from the same problems. Though there are *rules* in mixing, they cannot be easily proceduralized and applied in a consistent manner. They must be adapted for application in particular circumstances, adjusted according to a mixer's preferences, and very often balance technical consideration and aesthetic discrimination. It is extremely difficult to distinguish among technical, creative and aesthetic tasks. At some level, even *technical* standards are the result of wide-scale agreement about aesthetic judgements, about how recordings should sound. Also, mixers are not always consciously aware of whether an action is technical or aesthetic. For example, compressors may be used for the timbral effects or color rather than for dynamic control [14]. Hence, even assuring that compressing is a purely technical mixing process or determining what about the task is the technical component is not straightforward because although there are common *best practice* workflows associated with compression, engineers modify and personalize their workflows and rules are not necessarily strictly adhered to.

IMS designers have some possible solutions for addressing these ambiguities. Firstly, a number of different analysis and automatic tools and techniques can be used within the same system. The users choice of tool and technique may be matched to the context of a mix being produced [15]. The real challenge in producing IMS with some utility, is to create something that is able to represent the breadth of the music production field, support an engineer moving in a particular direction, yet not dictate or predetermine the process. The system's capability or intended purpose must be transparent, so that the users can dictate the direction of the work. In this way, the tool could facilitate the use of its *intelligence* wisely, in a given context and to an intentional end, as opposed to allowing the system's functionality to dictate mixing practices. This has been a concern with CAD. As will be discussed later in the paper, CAD has been shown to dictate the designer's process in some cases; though it has been suggested that this may be avoided. To achieve the desired independence, in CAD and in IMS, we have to recognize that the computational system and the human system are not redundant. Bernal et al. reminds us about CAD, "When characterizing the role of computers, we need to realize that what is in the mind of the designer and what is represented in the computer are not the same... The formalization of a design through a model does not necessarily correspond to the complexity of the entire design itself. In fact, computer programs are integrated in more complex cognitive systems" [16, p. 164].

4 IMS in the mixing workflow

Technological capability is only one aspect of how mix engineers conceive their problem space, or the set of potential issues and solutions they must resolve. It is one component of a very multilayered cognitive system, with many possible inlets for an assistive IMS. The current state of IMS has drawn a lot of attention to the technical, objective components of mixing, which is muddling our understanding of the subjective, a context and content-driven process of music mixing. Confusing matters further, the complexity of IMS technologies is rapidly increasing as smart technologies appear more and more capable of performing *humanistic* tasks. The advances in these particular type of technology further eclipse the fact that mixing is also in a continuous state of evolution and reinvention. The traditional studio paradigm, for example, has in many ways been usurped by the laptop producer, who often relies on different tools. None of these developments are necessarily deleterious for the practice of mixing but highlight a change, and a shift, in attitudes [17]. The current limitations of IMS are not an encumbering issue either. All technologies have limitations. The pressing issue now is that while incorporating IMS into current mixing workflows, IMS functionality is too easily confused for fully automated mixing rather than as an assistive tool.

For example, intelligent music systems are presently able to produce mixes with attributes associated with particular genres. They are capable of rendering recognizable, conventional sounds or making recommendations to users so that they can achieve them. They may suggest adjustments that make the spectral balance of mix typical for a particular genre. However, mixing is not merely a process of matching conventions and norms. These recognizable results in IMS are the product of mixing rules constructed from explanations in the practical mixing literature and practitioners experience and conventions. And/or, rules can be derived by extracting sonic features [18], from existing mixes that are deemed to represent what is typical. Mixes are compared to determine what is conventional. The professional mixer, in every mix, not only has to choose among existing conventions, but also make them relevant in the current context while adding something new. Mixers acknowledge this and develop a sense of *appropriateness* to guide their choices. For example, they understand the impact that different types, and styles, of compression will have on the perceived musical style [7] within a given musical and mixing context.

Amabile says that determining and understanding appropriateness is an essential part of creative activity. "Creativity is the production of a novel and appropriate response, product, or solution to an open-ended task." [19, p. 3] A response is *appropriate* if it is "valuable, correct, feasible, or somehow fitting to a particular goal" as determined "by people familiar with the domain in which it was produced." [19, p. 3] These evaluating people must be familiar with the conventions of the domain, not technology. Conventions are therefore as important to the engineer's creativity as appropriate novel responses. Whether an IMS can facilitate in the creation of novel responses depends on how and when the mixer utilizes the system to match norms.

4.1 Technical and aesthetic intelligence

Mixing involves both technical and aesthetic, objectively and subjectively evaluated, decisions and skills. Mixers cannot selectively choose to make one or the other type of decision. The product being delivered has intrinsic artistic value to its audience which requires technical skills on the part of the mixer. A mix engineer's sense of appropriateness attempts to balance the technical and aesthetic. For example, in many genres of music, certain types of distortion are praised for their timbral coloration attributes, but in other styles, distortion may not be considered appropriate. The context is all encompassing and important. A mixers' skills and mixing decisions are ultimately a synthesis of technical and aesthetic perspectives, and putting both together is often a creative act. However, creativity is not synonymous with aesthetics. There are creative technical solutions, just as there are creative artistic solutions. *Creative* typically refers to a property of a process in which a solution is formulated or chosen that results in an atypical realization [20]. Technical skills, artistic skills and creativity all have a place in mixing practices and workflows. IMS may play a role in facilitating any of these activities. However, if IMS creators either conflate these three components or arbitrarily split up the intelligences that meld them together, then the utility of incorporating IMS into a mixing practice or workflow is unclear.

Some IMS research claims to "take care of the technical aspects and physical constraints of music production" [6], and that the automatic solving of technical issues enhances creativity [3]. Others have explicitly stated that the technical and creative aspects are distinct enough to be separated, and suggest it is possible to "take over the mundane aspects of music production, leaving the creative side to the professionals, where it belongs" [21]. The definition of what constitutes a technical task is not consistent or well defined, but the implication is that a technical task is a laborious one that impedes creativity. In the same literature, descriptions of what constitutes a non-technical action in mixing remain vague. Admittedly, the practical mixing literature offers little clarity on the aesthetics of mixing. Interestingly, the musicology and record production research literature are making more of a contribution here [22]. A problem with these discussions is that the terms artistic and creative are being used interchangeably. The artistic aspects of mixing are associated with a mixer's subjective perspective. That often involves creativity, but ideally mixers will find creative technical solutions too.

Nevertheless, the argument that minimizing mundane and laborious tasks may aid creativity has been made elsewhere, and is well worth considering here. Csikszentmihalyi posits that creativity happens when creative thinkers enter a state of *flow*. Flow is achieved when, in an activity, there is a balance among control, deep engagement, and an appropriate level of challenge [23]. Too much or too little control inhibits agency, as does too little or too great a challenge. Assistive technologies, like IMS, presumably encourage flow by simplifying, if not fully automating, mundane and/or exceedingly complex tasks. In this regard, IMS may facilitate creativity without ever disentangling the aesthetic tasks from the technical ones. At the same time, automation might simultaneously be obfuscating a mixers' creative intentions, should those intentions necessitate managing the same mundane or challenging tasks in a novel way. It is hard to deconstruct IMS use cases, without first considering some of the factors that influence how mixer engineers practice their craft.

There are several conspicuous factors impacting how engineers approach the mixing process, making mixing decisions. A mixer's experience influences what they envision as a possible outcome when realising a mix. The organisation and administration of the mixing process (eg. track order, colour coding and sub-grouping) may impact the project complexity and therefore the decisions that are taken. Engineers naturally differ in their appreciation for mixing rules, conventions, best practices, and what may be considered common sense in mixing practices. Mixers also differ in how they explore mixing as a problem space, and in this, how they interrogate technology for its potential applications.

4.2 The role of experience

Some of these variations are due to experience. Mix engineers vary in experience. In general, experienced mixers will have spent more time using a greater range of technologies. This builds familiarity with use and misuse of technology in numerous different situations. This may also lead to skepticism about new technologies. Experienced mixers will have listened to more music. They have bigger *aural libraries* [24] filled with examples. They have completed more projects and made more observations of the impact of mixing decisions on the sound of a mix, on clients and on audiences. Similarly, Schön refers to design as a *reflective practice*. "Designers appear to build up their knowledge in a cumulative fashion, developing knowledge in one design episode and carrying it over to the next." [25, p. 182] "[P]ractised designers, especially the more skillful, tend to treat each design situation as a unique *universe of one* " [25, p. 181]. Experienced mixers are better prepared to adapt their skills and knowledge to the particulars of each project.

Experience creates more opportunities to interact with clients and grow to understand client needs, concerns and expectations. Experience also allows more time to develop a professional reputation, which requires consistency to maintain and protect. As a result, having observed the impact of many mixing decisions, experienced engineers may be more conservative about the decisions they make, to protect their reputation, particularly if they are directly linked with client expectations. Mixers test and adopt methods congruent with their levels of experience and the depth of their expertise. If an engineer has a deep understanding of particular type of signal processing, for example, they can make informed decisions about modifying that processing. They also have the critical listening skills and a developed epistemic perspective to evaluate the results. They know what they want to do, and they have expectations about how it should sound. It is likely therefore that experienced users will have specific expectations of IMS, what it should do, and how it could fit into a well-practiced workflow.

The mixer's understanding of the mixing problem space and potential solutions are influenced by prior mixing experiences, understanding of specific project requirements and client expectation. Understanding grows with experience. Lesser experienced engineers have not had the time to develop comparable depth of understanding and skill. Their practices and workflows are in a state of rapid development, where a lot might be tried out. But, they have had fewer opportunities to test and evaluate the results. They have had fewer opportunities to measure their decisions against the expectations of audiences and clients. Their intentions are less well formulated because they have yet to learn what potentials exist. They may know in broad terms what they want to do; they are less certain how exactly to realize it in a mix. And though they may have expectations about how it should sound, they have had fewer opportunities to link decisions to outcomes. Given this, a less experienced mixer may be inclined to deliberate more on the impact of making a particular decision. This takes time and effort, and therefore, they may be more open to the epistemic evaluations of others, including technological others. Less experienced engineers may be more prone to taking direction from an IMS.

Research from the EPSRC funded project, FAST (Fusing Audio and Semantic Technologies) has identified three levels of expertise in engineers [8]. As consumers and users of mixing technology, each have different expectations and motivation. The professional expects a finished result using a highly focused and streamlined workflow, developed over a long career and relying on experience. The novice is quite often not sure what to expect and is happy to allow *happy accidents* to dictate and determine workflow. In between is a professional-amateur (Pro-Am) who wants professional results but does not care much about how those results are achieved. Professionals apply solutions with intentionality. "Intention is directed towards a goal; it is a *purposeful*-ness of actions" [26]. For the Pro-Am, intention may, according to Mele, be satisfied by "judiciously selected examples of action" [26] such as those codified in an IMS. The professional-amateur (Pro-am) is probably the one who will benefit most from assistive technologies like IMS. Pro-Ams carry just enough knowledge about mixing to be able to interrogate the system and make some or semi-informed decisions; but unlike the professional, they do not necessarily know how problems are to be "tackled in an *immediate problem space* " [4, p. 139]. They are not necessarily sensitive to the uniqueness of each context. In their hunger to develop knowledge and skill, the Pro-Am is vulnerable to making the mistake of confusing mixing rules as defined for an IMS, with rules as an experienced human mixer appreciates them. IMS rules (help the mixer to) generate sounds that are recognizable as conventions. This capability relieves the Pro-Am of the labour of emulating conventions. However, it does nothing to guide them through the process of adapting those conventions to a particular production to ensure their relevance.

4.3 Interrogation and Creativity

Mixing is a process of solution seeking not merely solution applying. Designing similarly, even with the advent of CAD, continues to involve a "noticing and evoking mechanism", a form of "knowing-in-action". [4, p. 138] Mixers too decide and act in context. Just the music listening part, says Bamberger, is a kind of "perceptual problem solving", "the mind is actively engaged in organizing incoming sensory material... What we hear depends on what we are able to think of to hear" [27, p. 123]. Both the understanding of the context as well as experience influence what the mixer thinks to hear. IMS can play a role in this perceptual-cognitive back and forth, if the engineer uses it to explore the defined problem space. Based on experience, the mixer will impose goals, constraints or strategies on the process of searching for solutions. The mixer has a set of case-specific and experience-based heuristics which may be used to interrogate the innumerable possibilities, technological affordances and decisions. This ability to interrogate is at the heart of bringing creativity to mixing. Again, that creativity may lead to technical and/or aesthetic solutions; but in either case, the mixers' interrogations guide them towards solutions. IMS may eventually play a (more substantial) role in facilitating creativity in mixing.

5 Lessons from CAD and Related Fields

As IMS moves forward, both systems designs and its use in practice might take some cues from CAD to maximise its potential. Robertson and Radcliffe [28] have identified several positive and negative effects CAD may have on the design process. They conducted a case study and survey of CAD users to observe CAD's effects and assess its impact on design practices [28]. The positive effects include, as has been proposed for IMS, that CAD tools free up design engineers from excessively detailed work, and that leaves more time for creative activity [29]. It is also suggested that CAD facilitates the creative process through enhanced visualizations that improve design teams' abilities to "visualize and communicate" ideas as work progresses. CAD has not been observed aiding the ideation part of creativity [28, p. 136]. Bernal et al. [16] describe the negative effects of CAD as follows:

– *Circumscribed thinking*. The (design) alternatives thought to be possible or available are those that may be rendered with the particular tool being employed. (This may have direct analogies in mixing.)
– *Premature fixation*. As the designer works with CAD, the CAD computational model (i.e., the designed representation) becomes more and more complex. As the representational complexity grows, designers may show increasing resistance to major changes. (In audio, this would mean as the processing in the mix, the automation, etc. becomes more elaborate and intricate, the mixer may grow more reluctant to undo, redo or make major changes.)
– *Bounded ideation*. "The distraction from actual creative tasks resulting from technical and software issues" [16, p. 164]. Additionally, "Most design tools have a significant cognitive cost" [30]. Designers spend a considerable amount of time attempting to interface their work rather than focusing on the design itself". [31]
– *Experience* and *instinct* are circumscribed by technological limitations [16, p. 165].

These problems were evident in Robertson & Radcliffe's case study [28]. There they found that the functionality of the CAD system limited the solutions the team perceived to be available to them (circumscribed thinking). Furthermore, possible ideas were limited to the *easiest* ideas, possibly due to operating under time pressures [28, p. 136]. Alternatively, systems that allowed "too much creative freedom" led to "unnecessary complexity" and thus "wasted resources". [28, p. 137] "As the CAD models became more detailed during the course of the project, there was a strong disincentive to make major changes to them." [28, p. 136] As users developed proficiency with a CAD tool, designing changed. Their designs became more complex, and transitioned from "simplicity and sufficiency", and eventually to "excellence and even perfection" [28, p. 137].

Robertson and Radcliffe surmise that to avoid bounded ideation "the best environment for idea generation tended to occur away from computers, in small meetings, characterised by large amounts of sketching and discussion." [28, p. 136] The authors note that one *danger* of *constant* CAD use is that it cuts designers off from "ideas and experiences" but this could be enhanced or overcome through collaboration [28, p. 143]. Also, "when a detailed CAD model is displayed, it can convey an illusion of completeness that tends to discourage creative thought in a group situation." [28, p. 136]

Robertson and Radcliffe's survey [28] provided additional insights. In this survey, 88% of the respondents were "experienced CAD" users. This possibly skews some of their findings. [28] Nonetheless, the survey results largely reinforced their interpretations of observed interactions with CAD. Respondents typical felt that CAD did not facilitated communication among groups of designers, and was generally most useful for mature design. Only 25% indicated that they were not impacted by circumscribed thinking. "Just over half showed that they do sometimes become so enamoured with the power and functionality of the CAD too that they go beyond merely satisfying the requirements and aim for *perfection* [28, p. 142]. Interestingly, one respondent remarked, "The tool leaves traces. One respondent stated: "I can walk through a store and frequently tell what software certain products were designed in" [28, p. 142].

There were signs that users adapted to tool use too, for example, 45% of respondents claimed that they "delayed the implementation of a highly complex model", thereby avoiding the issue of early fixation [28, p. 142]. Overall, the authors conclude that CAD can enhance creative components of the work [28]. They recommend that "[u]ser manuals, tutorials, training courses, and pop up *tips* are perhaps appropriate places to make users aware that good design practices do not always involve sitting in front of a computer" [28, p. 143]. Given these findings, it appears that, in audio, teaching novice mixers to use IMS to its best advantage would be prescient.

5.1 Experience

In Robertson and Radcliffe survey respondent's experience/expertise with CAD correlated to their responses. They found that "experienced designers are more likely to be driven by requirements and not affected by circumscribed thinking." [28] Also, experienced users made less use of features that parameterized CAD models. [28, p. 142] Dorst remarks, "[W]e find that how designers perceive, interpret, structure and solve design problems cannot really be understood without taking their level of design expertise into account." [4, p. 135] A novice follows "rules to deal with problems". "A competent problem solver... selects the elements in a situation that are relevant, and chooses a plan to achieve the goals" [4, p. 143]— "the reflective paradigm becoming more relevant the closer we are to expert behavior." [4, p. 144] Tools for experienced users would assist in this reflection. Bernal et al. conclude, that for CAD to evolve, "the most fundamental is the need for a better representation of the tacit aspects of design knowledge before any computational implementation" [16, p. 177].

6 Adopting IMS

Like any new technology, mixers will incorporate IMS into their practices in a variety of ways and for different reasons. When the Autotune algorithm first became publicly available, it was not used to perform the micro-tonal corrections it was designed for, but instead, it was misappropriated to produce an electronic phasing sound, the phase vocoder. Today, that unintended sound is a mixing convention. Technology itself does not limit creativity [32, 33]. However, the design of technology, discourse about its use, and education may all shape how technology enhances creative practices. In this respect, IMS, machine learning and artificial intelligence are, in most respects, no different to any other audio technology development.

6.1 Adapting Mixing Practices

As mixers discover more and more smart tools amongst their plugins, and as interest in IMS grows, mixers are likely to encounter similar opportunities, issues and pitfalls encountered by early CAD users. In particular, mixers might suffer from "circumscribed thinking" [16], and conceive of mixing possibilities that are convenient to produce using the assistive mixing tools at hand. If major changes to the mix require deep-level interactions with an IMS, as the mixing process develops and the mix becomes more complex, they may be increasingly disincentivized to make significant changes [16]. refers to this as "premature fixation". On the other hand, studies on CAD use have also revealed a tendency towards perfectionism in some users. In music production, even before the availability of intelligent technology, mixers have been tempted correct and fix all the human elements out of musical performances. In many cases, this can prove aesthetically problematic, but perhaps the best way to address this problem is through education and discourse. Likewise, IMS, because it can be used to match standards and conventions, might be mistaken for expectations and thereby inspire mixers to strive for some kind of absolute conformity to computer assisted recommendations. Perhaps one of the most important warnings to heed from CAD is the impact of computational support on social interaction. The nature of the assistance IMS can even now provide might make ideation with other humans (e.g., clients, artists and colleagues) appear superfluous. Mixers may avoid feedback from human critics and grow increasingly reliant on IMS as an epistemic tool.

However, none of these drawbacks are inevitable. As studies on CAD have shown, how and when IMS is being incorporated into a mixer's workflow can make a difference. For example, rough mixes might facilitate discussions with other humans, particularly with clients. In this way, IMS can actually facilitate social interaction. Future IMS systems may even include social, communication-oriented functionality that encourages users to interact with other human listeners. The issues of circumscribed thinking, fixation and perfectionism might be addressed by systems functions that track user behaviour and provide feedback and/or query users regarding their intentions. A less *big brother* type solution would be to encourage users to develop experience, perhaps by building educational functionality directly into the systems themselves. There is an argument that less experienced mixer benefit more from IMS tools as they currently stand. Less experienced mixers have enough knowledge to interrogate the system's functionality and choose actions that lead to appropriate, though conventional, solutions. This, however, touches only the surface of the craft.

6.2 Pedagogy

Experience plays an integral role in how IMS are viewed and used, so it is worth considering how audio pedagogy can shape the future of IMS and IMS use. Providing students with a holistic view and strong conceptual foundation for recording and mixing can help to avoid some of the traps of computer assistance. Furthermore, specific learning outcomes can be created to prepare students to make the best use of intelligent tools.

In a case study on the impact of CAD on engineering design education, Robertson et al. identified several ways that CAD tools affected students' critical problem solving [34]. They observed that CAD enhanced visualization and thereby communications around a CAD models. At the same time, many students assumed that the CAD model was sufficient for communicating about a design, and as a result they did not develop other skills that facilitate communication, for example, sketching skills. Sketching not only aids communication, but also problem solving. In a related investigation by Robertson et al. it was noted that students lacked a "critical dimension" in thinking which allowed them to adapt CAD models for real world manufacturing [34]. The experience of learning CAD led students to assumed that if they knew how to use CAD, they knew how to design [34] They "did not appreciate the iterative and sometimes ambiguous nature of the design process." [35, p. 4]

Some of these issues are already familiar to audio education even without IMS in our curricula. Communication and problem-solving skills are recurring themes in the audio pedagogy literature, and the design literature suggests that these skills will become ever more important as the sophistication of intelligent technology grows. In addition to preparing students to think about the needs of the mix rather than the capabilities of the tool, students need to develop epistemological perspectives. They need methods for evaluating work other than, or in addition to, recommendations from an intelligent, assistive technology. The more students and novices understand the complexity of mixing and feel confident in their abilities to assess their own work, the more likely that they will explore the creative, craftful and artful possibilities IMS has to offer.

7 Conclusions

There are numerous potential benefits to incorporating IMS into mixing workflows. By simplifying or automating repetitive and mundane mixing tasks, it can aid the creative flow, and experienced users may find in these tools new means to explore creative options. However, it should also be considered that less experienced users may find their thinking circumscribed or bounded by the functionality these tools offer. In understanding and preventing these issues, both mixers and IMS designers have much to learn from CAD. Both system design and education have roles to play shaping how IMS technologies are applied in mixing practices.

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