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Interactive Learning Environments for Motorsports Racing

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Abstract This chapter explores how computer-based motorsports racing simulation games, game play, and sim racing user interfaces serve as immersive interactive learning environments (ILEs). Such ILEs typically provide a constructivist learning experience through 3D dynamic graphic animations that are jointly controlled by the underlying game, automated bots that may control simulated race cars during game play, or alternatively other people engaged in a multi-player racing game competition. The user interface devices that situate and enable player-driver control of their in-game simulated race car also act as affordances that enable/sustain an immersive, high performance driving and learning experience. This article reviews these capabilities, along with assessing the efficacy of how they may affect the development of expertise, knowledge transfer, and cost functions through different system configurations.

Keywords Motorsports racing games · sim racing · verisimilitude · kinesthetic immersion · expertise · knowledge transfer

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TBD.1 Introduction

What are the best ways to learn a subject? What are the most effective means for delivering procedural and experiential educational content that is easily learned? When and where should interactive media like computer games or virtual worlds be used to facilitate knowledge acquisition, transfer or application in practice? Open-end questions like these underlie motives for the development and deployment of interactive learning environments (ILEs).

Following the *Journal on Interactive Learning Environments*, an ILE is a system built in software and sometimes with specialized hardware designed to support teaching and learning in education. The interaction in the system can be between the learner and the system, the teacher and the system, or between teachers and learners with each other using the system. The learning can be academic, informal, or work-related. But such a characterization leaves a lot of room for interpretation of what is an ILE, and what the requirements are for different ILEs.

Is there a single set of technical requirements for ILEs to satisfy that will be most effective with socially diverse audiences of students or learners? Not likely. Do different kinds of subjects to be taught and learned require different kinds of technical system requirements for learners with different levels of cognitive, neurocognitive, or physical abilities? Most likely. Thus, the socio-technical contexts and ecosystems that situate the development, use, and evolutions of an ILE will both facilitate and constrain the technical processing requirements to be articulated, and potential user experiences to be delivered. This article examines such matters within the domain of high performance motorsports racing where cognitive, neurocognitive, and physically embodied knowledge, skill, and practice must be learned, applied and refined. Why?

First, each year millions of people seek to learn how to safely drive a motor vehicle like a car, truck, motorbike, or mobile heavy equipment, pretty much in any land occupied by people. The global automobile and ground-based transportation industries depend on competently skilled drivers operating their vehicles in a safe, effective manner. In addition, new firms that offer ride-sharing services through contracted drivers engaged via Internet-based mobile apps like Uber, Lyft, and DiDi, now employ tens of millions of such drivers worldwide (Reuters 2018). Thus there is global demand from people who want to learn how to drive and realize the vehicular mobility opportunities, while avoiding potential negative outcomes (e.g., driving accidents, traffic congestion, exhaust pollution) . But driving can also be fun and challenging in particular situations where the limits of driver performance can be safely engaged and assessed.

Second, what does a student who wants to learn to drive a vehicle like an automobile need to know in order to drive efficiently and effectively? There are many diverse answers to such a question. For example, a student can enroll in a course to learn the laws and regulations affecting safe driving practices, as well as how they are put into practice while learning how to safely operate their motor vehicle in various driving conditions. The ability to know and recall accurate declarative knowledge details about driving laws and regulations are necessary to pass a multiple choice test to earn a driver's license. Curricular pedagogy for the kind of education and learning implied usually amounts to reading, remembering, and recalling relevant details that are gained through engagement with a driver's license preparation guide. Nothing special about that. On the other hand, actually being able to safely operate and control a motor vehicle on open roads with other vehicles and pedestrians, does entail learning how to behave and think-through continuously emerging driving conditions within physically situated worlds, via tangibly embodied (automobile driver) user interfaces and control apparatuses (Gibson and Crooks 1938). Car driving test simulators can help would-be drivers to learn how to take and successfully complete an in-car driving skill test. Furthermore, Chan and colleagues (2010) argue that in the case of subjective judgement knowledge regarding hazard anticipation, speed management, and attention maintenance skills, training in driving simulators clearly enable new drivers to learn and improve core driving and safety skills. This is much like the situation with flight simulators designed to help both novice and experience aircraft pilots acquire or refresh their behavioral piloting skills (Bernard 2012). The efficacy of subjective judgement in automobile driving requires embodied driving experience, rather than primarily declarative knowledge. Furthermore, learning to operate an automobile in the physical world often occurs with a personal tutor or driving coach sitting next to the driver student. Learning how to drive in this way can be risky for the student, tutor, other drivers and pedestrians. So there is great practical and safety needs for enabling students to learn both the rules of the road, and safe vehicle operation in somewhat familiar and unfamiliar circumstances.

Third, motorsports racing is also a global industry that entertains millions of spectators who watch race broadcasts or attend on-site motorsports events. Motorsports racing is generally not a subject taught in higher education institutions, yet high-skill drivers engage in motorsports as a hedonistic pleasure, amateur hobby, or professional occupational career. Learning how to drive fast in ways appropriate for motorsports competitions often is best learned and practiced by first driving slow, underpowered cars more precisely and more effectively under evermore challenging conditions (Kinard 2017). Such deliberate practice driving has no spectators, and many contemporary motorsports driving games (described later) encourage progressively challenged practice driving in order to learn how to drive fast, more competitively, and with greater expertise.

Fourth, the entertaining visibility of motorsports racing may encourage some ordinary drivers to attempt to develop racing skills and expertise on public roadways. However, this is clearly unsafe and can precipitate dangerous consequences to themselves, other people or property. Consequently, there is need for ordinary drivers who have competitive motorsports racing inclinations to have a safe, low-cost venue to satisfy their desires.

Fifth, because of the professional career opportunities, technical (subject matter) expertise, industrial workforce development, and institutional support for competitive motorsports is an interesting domain to examine for ILE development, application, assessment. The need for mental models of knowledge of closed racing courses, managed race conditions, and controlled safety requirements for motorsports racing, motorsports race driving skill mastery and subject matter recall, are also topics to be learned and mastered by would-be racing drivers. In this regard, can ILEs for motorsports driving afford highly accomplished, expert levels of driving performance, speed control, dynamic hazard recognition, and precise attention management, rather than just assisting novice drivers to learn basic driving skills?

Last, fast-paced, action-oriented computer games are being recognized as constructivist ILEs, whether by circumstance or by design (Jong, Shang, Lee 2010). Such games are commonly intended for entertainment, fun and game-based play, rather than as ILEs intended to support an academic curriculum or formal instructional pedagogy. But game play-based learning can be demanding, serious, and hard work. First-person perspective motorsports racing games, where you see a partial representation of yourself as driver (i.e., the driver's viewpoint situated within the driving cockpit that visualize the driver's hands and actions on the steering wheel) can be found in this category. These conditions include weather variations, undulations in track surface, complex vehicle configuration settings and pre-race tuning adjustments, tire wear, in-race collisions that result in simulated vehicle damage, monetary prizes, and more.

As described below, motorsports games, game play, and “sim racing” platforms can serve as immersive, embodied, and tangible virtual world-based ILEs that support constructivist capabilities for interactively learning high-performance motorsports race driving skill and race driving practice. How might this occur?

TBD.2 Related research

The theories, concepts, empirical studies and interpretations that inform this chapter are drawn from two general bodies of research. One is automobile driving with a focus on education and learning how to drive, and the other is alternative conceptualizations of learning and transfer of learning that can be realized through ILEs.

TBD.2.1 Learning how to drive an automobile

As already noted, driving an automobile is a complex sets of tasks requiring diverse skills and performative abilities in a variety of driving conditions. Empirical studies of what is involved in learning how to drive an automobile date back at least 80 years (Gibson, Crooks 1938). More recent research reviews have addressed topics such as the roles, affordances, and efficacy of alternative configurational designs of automotive human factors whether for driver controls, displays and measurement guages, sightlines and field of view, driver’s workspace (seating, ergonomic affordance positioning, comfort, climate) driver readiness (e.g., fatigue and impairment conditions), driver assistance systems (skid resistant vehicle braking), or driving behavior (Akamatsu, Green, Bengler 2013). At the practical end of the automobile driving literatures, there are many informal online resources and “instructional” videos that offer guidance, information, and education in how to drive an automobile (DriversEd.Com 2019; Virtual Driving Interactive 2019; wikiHow 2020). In between are recent literature reviews and assessments of what researchers in automobile driving education have investigated and determined so far.

Much research and educational attention addressing automobile driving is directed to what to teach and how, in order to help new/young drivers to drive safely. New student drivers need to learn, practice, and experience safe driving behaviors. For example, Mayhew and Simpson over more than two decades have reviewed studies originating in different countries, with particular attention directed to the efficacy of driver education on safe driving behaviors practiced by new driving learners (Mayhew, Simpson 1996; Mayhew, Simpson 2002; Mayhew 2007). They report that the international studies they reviewed provide little support for the hypothesis that formal driver education, both in-class education and in-vehicle training, is an effective measure for improving safe driver practices. In contrast, they report that graduated driver licensing systems (GDLS) which give learner drivers an opportunity to gradually acquire more experience and skills as drivers over time (e.g., a driving career of 6-18 months) in low-risk environments are better associated with safe driving practices and outcomes in the years of driving that follow. Empirical studies such as those in Sweden (Gregersen, Berg, Engsgtrom, Nolen, Nyberg, Rimmo 2000) and the United States (Shell, Newman, Cordova-Cazar 2015) demonstrate these results across driver population sample that vary with respect to gender, race/ethnicity, median household income, urban-rural residence and teen driver age.

From this line of research, it appears that new drivers need extended periods of driving practice and experience in progressively more challenging (yet safe) ways, supplemented by educational regimes that stress how to safely operate an automobile and drive safely in different driving kinds of situations, conditions, and vehicle configurations.

TBD.2.2 Learning theory and transfer of learning via ILEs

ILEs are not a singular technology nor system configuration. ILEs are not traditionally conceived nor designed to support complex, sustained performative and neuromotor control behaviors, such as might be required to support students learning how to drive a motor vehicle. So if a new category of ILE is needed for such an educational purpose, then what theories and concepts from studies of learning, and transfer of learning, may inform ILE configuration and capabilities for learning how to drive, as well as how to drive under different challenging conditions? These foundations are identified here.

Among the earliest approaches to education and instructional design can be attributed to Aristotle. Aristotelian cognition and learning was expected to arise by engaging students with lectures, and sometimes observational materials, that are juxtaposed with questions the students are suppose to answer by reasoning from what is already known or what has been provided. Such cognition is now seen as static and pre-conceived. In contrast, pragmatic 20th. Century educational scholars like John Dewey and others recognized and argued that education and learning by students needed dynamic and active experiences, needed to be cognitively challenging, yet also be situated within common social and cultural conditions for such experiences to arise (Dewey 1938). This in turn gave rise to at least three bodies of literature that interpreted Dewey and others as stipulating that school-based education, learning, and translation of learning into practice (as a form of learning transfer) needs to be either more psychologically (or cognitive development) oriented, more socio-culturally oriented, or more constructively oriented, depending on the topic or problem domain to be learned. The development of alternative ILEs thus commonly drawn upon one or more of these three theoretical lines of thought. Here, the choice going forward is directed to a combined perspective as described below and labeled in this chapter as *constructivist learning,* that combines these lines of related research in ways that can enable learning transfer experiences and behavioral skill acquisition outcomes.

First, from educational psychology, the empirical study of knowledge acquisition for human behavioral skills and experiential performances, in particular those that entail sustain durations of performance to realize competence, fall under the category of expertise and achieving expert performance (Ericsson 2006; Ericsson, Hoffman, Kozbelt, Williams 2006). If learning how to drive safely, as well as how to drive under diverse driving conditions or challenges, then the helping students develop driving expertise and become expert drivers, is relevant. Ericsson (2006) in particular advocates the development of expertise and expert-level performance follows not merely from static or dynamic education encounters, but from a regime of *deliberate practice*--a designed curriculum that progressively poses evermore challenging practice performance conditions where the student is coached to perform tasks both at, and then beyond, their current level of skill competence. Students in these situations will experience failures. Failure experiences are in turn seen as actionable learning situations where the student is directed to reflect on, to mentally or behaviorally replay the failed experience, to identify behavioral or neurocognitive adaptations to apply that may overcome or prevent the failure, and then to repeat the performative task iteratively until the adaptation (or subsequent adaptations) prove effective in completing the challenge task without failure.

Translating deliberate practice into learning how to become more expert at automobile driving requires providing a safe platform for doing so. This recognizes that having student learners drive automobiles in the diverse conditions can be very unsafe and risky, and driving failures may incur high costs.

ILEs for automobile driving provide safe and low cost platform for not just learning how to drive, but for how to drive under increasingly challenging conditions that induce failures that the student can behaviorally experience and learn how to anticipate and mitigate. Whether and how students transfer such ILE-based experiences into physical driving practice remains an open question for future study.

Second, from socio-cultural studies of learning and learning transfer, students experiencing embodied cognition through socially and culturally situated materials (e.g., the configured driver's cockpit in an automobile), are relevant foundational concepts for ILEs. Socio-cultural student learning (Hasse 2015; Lave, Wenger 1991; Packer, Goigoechea 2000) involves becoming a peripheral or evermore central member of a community--e.g., people who are automobile drivers, and who must soon become safe drivers who respect and cooperate with other drivers on the road who they do not know. It involves constructing different genres of knowledge at various levels of expertise and physical embodiment through the use of available tools (Wilson 2010), along with recognizing situated affordances or their analogs the remind participants about what knowledge may be relevant in the situations at hand (Kaufman, Clement 2007; Norman 1999): what it takes to be an accomplished and safe driver; learning driving as a kind of work and its workplaces (cf. Billet 2001); what driving affordances and conveniences an automobile provides, where they are located/positioned, and when to utilize them (cf. Franchak, van der Zalm, Adolph 2010).

Socio-cultural learning also involves recognizing and respecting the consequences of socially undesirable behavioral performance--e.g., wreckless driving that may result in an automobile accident can be dangerous to one's self and others. Additionally, it involves practice-based learning tied to everyday meaningful use of material artifacts such as personal computers for playing games (Gee 2003), or automobiles with different capabilities including driving simulators (Chan, Angela, *et al*. 2010), as well as automobiles that operate on roadways, pathways, or dedicated close driving courses, under different driving conditions (e.g., driving in rain or on ice-slick roadways).

ILEs for learning the hows and whats of automobile driving behavior, of materially embodied driving artifacts, and of driving-as-work, should provide such capabilities and challenges that recreate and reinforce socio-cultural practices associated with automobile driving.

Third, from constructivist studies of learning and learning transfer relevant that incorporate ILEs, much recent attention has been directed at the emerging roles of computer games and simulated virtual worlds as learning platforms (Dede 2009; Jong, Shang, Lee 2010; Kafai, Burke 2015; Scacchi, Nideffer, Adams 2008). These platforms can provide engaging pedagogical contexts in which learning can take place within specific and replayable conditions through interactive, immersive user interfaces (Dede 2009; Dunleavy, Dede, Mitchel 2009). Computer games and simulated virtual worlds allow student learners to observe, reason about, apply, succeed/fail in the tasks at hand, and reflect on what they know or have learned through interactions with these platforms (Dede 2009; Scacchi 2010a). In addition, part of what further enhances the immersiveness of the user interfaces is the provision of digital affordances (Dalgarno, Lee 2010; Dunleavey, Dede, Mitchell 2009) and interaction control devices like keyboards, touch pads, steering wheels, joysticks, etc. that allow for embodied cognitive action, experiential neurocognitive enrichments (Clemenson, Stark 2015; Green, Bavalier 2012; Mishra, Anguera, Gazzaley 2016), as well as the physical and virtual co-presence of others (Scacchi 2008). Immersive learning potential is further enabled and accelerated through representationally and experientially authentic play-work situations and learning activities in domains like high-performance simulated driving (Scacchi 2018).

Overall, ILE platforms that bring together computer game-based play with authentically simulated virtual world environments capabilities serve to nurture and transform not just the student learners, but also the teachers, families, and social settings that come together to realize socially constructive learning experiences (Balienson, Yee, Blascovich, Lundblad, Jin 2008; Scacchi, Nideffer, Adams 2008).

Building from these three lines of scholarly research on learning, together with the limited research on learning how to drive modern automobiles under various physical conditions and settings, our interest going forward is identifying how computer games that focus on motorsport racing serve as a paradigmatic model for ILEs that focus on student learning practical behaviors and embodied actions that support articulate development and transfer of authentic skills that can span a career in a specific industry.

TBD.3 Constructivist Learning Modalities for ILEs

Constructivist learning paradigms stress that cognitive reasoning abilities and performative skills are effectively acquired through instructional design and pedagogical scaffolding. Such design and scaffolding are provided by educators/trainers, together with sustained engaging practice and reflective self-assessment by learners. Such instruction, scaffolding, practice, and assessment should accommodate coaching or automated guidance, incremental performance monitoring, and continuous feedback on progress. Instruction, scaffolding, practice and assessment should incorporate the presence of progressively leveled challenge trials and errors to realize subject matter or performance skill mastery. Errors in particular are seen as a key learning resource, especially when they are situated in a separable/embedded context that triggers a reflective learning moment (cf. Ericsson 2006). Additionally, the presence of other participants who can be observed to be engaged in learning similar matters (i.e.,via social and observational learning) should be part of an enriched learning environment. Subsequently, errors made by other nearby learners are valuable when the focal learner can compare the error's pre/post-conditions to correct/best practice.

Some learning practices entail body movement or human movement potential. This refers to the coordination of articulate body movements and proprioception that needs to become increasingly automatic (i.e., encoded into "pre-cognitive" motor control memory to support fast/agile human reaction). This is sometimes designated as *kinesthetic learning*. The engaged neuromuscular motor-control movements may be gestural, haptic, or tactile, and these bodied movements may be coordinated with multi-sensed (visual, auditory, translational force, etc.) observation and attention management. These movements may be associated or triggered by emotional states like excitement, fear, anger, ecstasy, disappointment, avarice and others. Such articulate movements are more elaborate tangible expressions of what can be done with a touchpad/computer mouse and user selection clicks, mouse cursor navigation and control via visual display, and enriched by audio speakers/headphones. Alternatively, these movements are motorcontrol movement skills that can be observed by a passenger who watches someone else drive an automobile in a demanding, sinuous roadway driving situation. Similarly, more exotic conditions are found and can be observed in flight simulators used to train military or commercial aviation pilots (Bernard 2012).

ILEs supporting constructivist learning can therefore rely on an pedagogical approach that jointly entails: (a) cultivating, testing, expanding and refining mental models of subject matter details and associations (also known as schematic knowledge acquisition); (b) data-driven experimentation and skill refinement, including trial and error guesswork and mistakes arising from attempts at knowledge application or deliberate authentic practice; (c) model-based cognitive reasoning for planning and problem solving; and (d) situated subject matter affordances that serve as reminders, scaffolding, infrastructure enabling embodied interaction experiences, or socialized learning situations (Johansen 1991; Scacchi, Nideffer, Adams 2008). This article describes how game-based race driving simulations and embodied systems enact such a constructivist learning paradigm for motorsports race driving skill development, expertise acquisition, and practice. Consequently, motorsports racing games, game play experiences, and game play systems can denote ILEs to such ends.

TBD.4 ILEs for Motorsports Racing Skill Acquisition and Development

Computer games are a mainstream, widespread kind of digital artifact recognized as affording different kinds of learning experiences (Dale, Jossel *et al*. 2020; Gee 2003). The genre of motorsports racing games accommodate a variety of user interface devices and play/viewing experiences that collectively serve to provide simulation-based entertainment (Racing Games 2019). In many contemporary motorsports racing games (*Forza Motorsport, Gran Turismo, Need for Speed*, etc.), the player-driver often plays against automated bots that control the observable behavior of other competing cars in a race course game level. Bot driving abilities can be set by users from easy to expert or aggressive, depending on the game and ther player-driver's desire for challenging driving conditions. These games are played world-wide by millions of players, and some represent billion dollar game franchises. Some of these games emphasize exuberant, fantastic, or "illegal" street racing game play experiences and high-flying driving-crashing antics within arcade-style game play, that some scholars fear may cultivate risky human automobile driving habits (Fischer, Greitimeyer, Morton, *et al*. 2009). However, there are no direct costs or safety risks associated with physical automobiles, nor physical harm to others or property when driving/racing virtual cars in computer games.

Other motorsports racing games focus on affording physically accurate, more authentic (simulated) racing conditions, and more challenging racing game play. Games such as *Assetto Corsa, DiRT Rally, iRacing, Project CARS*, and *rFactor* (and their current version releases) are regularly played and continually improved as dedicated automobile racing game simulators supporting "sim racing" (Sim Racing 2019) and virtual/mixed reality racing experiences (Broadbent 2017). Sim racing games, game play, and game system user interfaces also serve to deliver compelling learning experiences about motorsports race driving, vehicle dynamics, and vehicle tuning configuration settings (Hamaria, Shernoff, *et al*. 2016). Furthermore, in motorsports racing games, the player-driver often plays against automated bots—that is, AI programs that control the observable driving behavior of other competing cars in a race course game level, to help realize more competitive learning situations (Racing Games 2019). As before, bot driving abilities can be set by users from easy to expert or aggressive, depending on the game and the level of authentic racing challenge the player seeks to learn to master through practice and planning. It is this simulacra embodied in sim racing that draws our attention next.

In 2017, the McLaren (2018) Formula 1™ team began to organize and sponsor motorsports racing game tournaments. Their goal was to identify and recruit the best sim racing drivers for employment on the F1 team as professional "simulator drivers" that support the professional McLaren F1 racing team efforts (Gitlin 2017). Tournament play is only against other human competitors, but all competitors were expected to prepare and train with different sim racing games like *rFactor 2, iRacing, Forza Motorsports*, or others where they would compete and level up their driving skills against competitive race driving bots. Some sim drivers would also watch regular F1 races broadcast online, so that they could compare their lap times, driving conditions (raining versus hot weather, on-track debris that can suddenly appear then quickly be removed, vehicles colliding ahead, etc.), and simulated race car setups to those observed in actual professional races (Phillips 2015). Further, in anticipation of growing engagement of a new generation of F1 racing fans and sim racers, F1 drivers like Fernando Alonso (affiliated with Team McLaren at the time) has begun to invest in establishing professional eSports sim racing league teams that compete via human sim racing drivers (Noble 2017). In the U.S., the NASCAR stock car racing series is following a similar direction, with the recent announcement of the eNASCAR iRacing league, with teams affiliated with current NASCAR drivers William Byron, Denny Hamline, and Kyle Larson (Press 2020).

eSports is a rapidly growing global industry that attracts millions of online viewers who do not watch sports on television. eSports and motorsports racing games are also converging with autonomous vehicle technology, with the emergence of autonomous eMotorsports events, offering new modalities for learning and participation in motorsports, including from communities traditionally ignored or marginalized by the motorsports industry (Scacchi 2018). eMotorsports sim racing may thus serve as a new channel to capture and capitalize on emerging global interest in the intersection of motorsports game play and eSports, both as a global entertainment media enterprise and online (re)broadcast venue.

In the future, many sim drivers expect to be able to sign-up to access live race car telemetry to further tune the sim race car setups or settings, as well as to compare their resulting performance, all as part of a sim racing game experience (cf. Thompson, Blair, *et al*. 2013). Once such data sharing is enabled, it can also feed back in the other direction, so that professional teams can review what off-site sim race enthusiasts find may be more productive vehicle tuning settings based on their simulated experiences. Coordinating and aggregating the sharing of tactical telemetry data will then merit careful attention, once or if it offers to provide competitive advantage to the teams able to successfully affect such data sharing.

Thus, the embodied learning potential and interest in motorsports racing games merits close examination for how these games, game play experiences, and game systems (along with their user interfaces) collectively realize an immersive, constructivist ILE for motorsports race driving. Accordingly, there are at least three ways to evaluate the authenticity and efficacy of game-based ILEs for constructivist learning of a complex subject and performative skill domain such as motorsports racing and race driving. These focus respectively on: (a) immersive presence; (b) learning affordances; and (c) expertise development, knowledge transfer and cost functions enabling learning of persistent practical abilities. Each is examined in turn.

TBD.5 Increasing Immersive Presence for Learning Motorsports Racing Skills via Sim Racing

How do motorsports game play via sim racing mirror the technical arrangements and social order that surround motorsports? Are such reflections truthful renderings of the arrangements and order, or do they reflect views that distort such configured realities? Verisimilitude offers a lens through which such renderings may be observed and examined.

In literature, verisimilitude denotes likeness to the truth, such as the resemblance of a fictitious work to a real event. Fantasy novels and science fiction stories that discuss impossible events can have verisimilitude if the reader is able to read them with a willing suspension of disbelief. Verisimilitude links (re)cognition to both performative cultural practices and neurocognitive activity through symbolic and material socio-technical affordances (cf. Franchak, van der Zaim, Adolph 2010; Kaufman, Clément 2007; Kreijns, Kirschner, Jochems 2002; Wilson 2010). Computer games that mirror, recreate and rerepresent motorsports racing practices, artifacts, and social order with virtual race cars and racing simulation represent the form of verisimilitude of interest here. Accordingly, it is plausible to adapt the construct of verisimilitude for comprehending the game-based driving/racing experience as unspoken visceral narratives to draw attention to the authenticity, immersiveness, and near-transfer learning of simulated experience for avid sim racers and sim racing user experiences? Is motorsports verisimilitude mediated by the material artifacts that allow for further embodiment and recreation of simulated race driving actions, events, and experiences, but without the material, socio-economic or safety costs associated with professional motorsports endeavors? Such questions merit further consideration.

With sim racing, the motorsport game play challenge is to experience, embrace, and endure highly authentic vehicle and driving dynamics in simulated racing conditions (Sim Racing 2019). These virtual driving dynamics can be modulated by simulated variations in tire pressure and temperature, alternative drivetrain gear ratios, in-car cockpit driving views, suspension adjustments, visual replication of professional team car appearance, and timed/course lap constraints (e.g., 12 Hours of Sebring, Daytona 500), including periodic pit stops to virtually "re-fuel" and service the simulated racing cars. Sim racing enthusiast player-drivers further embrace the verisimilitude of high performance vehicle driving sensation through motorsports game design (vehicle and environmental surround graphics, observable vehicular physics, audio soundtrack, laser scanned digital race course models, etc.), user interface controls (game-control steering wheels, pedals, gear selectors, driving seat, wraparound displays, motion-control feedback) (Brennan 2017), immersive high-speed play-driving experiences mediated through embodied virtual user interfaces (Broadbent 2017), and competitive multiplayer sim racing events (FIA 2016; Gitlin 2017; Nissan GT Academy 2017; Watkins 2017). Such play-driving experiences are further situated in the immersive narratives found in online chat threads that compare sim racing to actual racing videos, as well as global spectator/fan discourse via social media.

In sim racing games, what currently escapes recreation are things like complex negotiations surrounding professional motorsports team formation and staff salaries, corporate sponsorships and team financing, news media engagement, commercial product endorsements, insurance and driver/spectator safety protections, circuit travel planning, equipment transportation logistics, and more. So motorsports and sim racing game play seems to limit the focus to what their game developers can recreate that focuses attention to the sensational and perceptual embodiment of motorsports race driving, while at present diminishing or ignoring an overlay of business matters, administrative governance, financial costs, economically viable motorsports workforce careers, extended travel schedules, recurring reorientation to new local environments, media coverage and promotion, engaging/avoiding spectators, racing accident injury and recovery, and safety risk management that enable commercial endeavors in professional motorsports racing.

Finally, it is worth noting that sim racing games and their advocates are currently biased in favor of play on personal computer and console gaming systems rather than mobile game devices. This is not to say that motorsports games don't flourish on mobile devices, since there are many popular racing games that are enjoyed by millions to hundreds of millions of players world-wide. Instead, that the culture of sim racing games, game play and play spectating/viewing are clustered by their enthusiasts into venues and social media that arrange, define, and distinguish merely entertaining racing games and game play from high authenticity, difficult-to-play sim racing games and kinesthetically immersive simulated race driving. Serious play with motorsports sim racing as immersive ILEs is further afforded via a commitment to simulated racing game tournament across multiple racing circuits (e.g., *iRacing* at http://www.iracing.com). This in turn commonly entails an investment in a sim racing rig, continuing engagement of professional motorsports media spectating, and online social discourse helps narrate, sustain, or elevate one's position in the world of motorsports racing game culture (cf. Scacchi 2018). Interest going forward in this article is limited to motorsports sim racing.

TBD.6 Affordances for constructivist learning via Sim Racing ILEs

Affordances refer to situated, interactional properties between objects and actors that facilitate certain kinds of social interactions in an enriched environment (Norman 1999). Performative actions, such as those arising when interactively manipulating user interface devices to control computer game play, facilitate recognition and perception of environmentally situated object affordances within the game during game play (cf. Franchak, van der Zaim, Adolph 2010). Immersive 3D computer games and game-based virtual worlds, when effective, afford new ways and means for collaborative learning (Dalgarno and Lee 2010; Dawley and Dede 2014; Kreijns, Kirschner, Jochems 2002; Scacchi 2010a; Scacchi, Nideffer and Adams 2008). Motorsports racing games and sim racing user interfaces devices thus help player-drivers to learn to recognize and act towards objects (e.g., other simulated race cars) and actors (bots or humans controlling these simulated race cars) observable within racing game play.

The concept of affordances also appears in the studies that employ the construct to characterize aspects of complex work settings that facilitate how people interact though computing systems (Billet 2001; Scacchi 2010b). Motorsports racing games and sim racing user interface devices are tools for learning simulated race driving. But they are also socio-technical conduits that afford shared sim racing experiences with other like-mined enthusiasts, as well as peripheral participation in motorsports culture (cf. Kaufman and Clément 2007; Scacchi 2018; Wilson 2010). These games, devices, and experiences jointly recruit learning how to be a sim racer and (simulation-based) motorsports race driver, and simulated race play competitor. Conversely, developing the self-identity of being a sim racing driver and competitor engenders desire for more authentic, more immersive sim racing technologies and play experiences with high verisimilitude.

Learning affordances, however, are neither universal nor ubiquitous. Similarly, they are not experienced in the same way in different settings. ILE-based affordances intended to facilitate learning may be more effective when specific to a subject matter domain, rather than generic or domain-independent. Accordingly, an affordance that enables or encourages certain kinds of actions in one motorsports racing game setting, may inhibit or discourage similar actions in another setting. Sim racing practices observed for one game may differ from another game, as do which social groups situate different practices. So details and settings matter in learning sim racing, much like they do with other ILEs.

At least seven kinds of socio-technical learning affordances routinely recur and accompany motorsports racing games, game play and sim racing user interfaces. Each is described in turn. This follows the approach previously utilized to examine the learning affordances for multi-mode, interactive game-based worlds informal science, technology, engineering and mathematics (STEM) education and industrial applications (Scacchi, Nideffer, Adams 2008; Scacchi 2010a; Scacchi 2010c).

TBD.6.1 Collaborative learning groups and group situations

What social or socio-technical groups situate sim racing and motorsports game events? Who participates within such a learning community, as well as why and how they participate?

In motorsports racing game play, there are groups that center around different socio-technical arrangements. These groups may focus on relationships among: sim racing experiences and user interface devices; professional motorsports teams or sponsors that act to encourage engagement with motorsports game play; online multiplayer motorsports racing cohorts who participate in scheduled online races with common racing games (e.g., *iRacing*); or motorsports game makers and downloadable content makers (game modders (Scacchi 2010c)) who collectively act to advance the authenticity and immersiveness of race driving experiences for motorsports game players. Audiences of spectators who view multiplayer racing game play competitions online (via YouTube or Twitch) are also emerging within the realm of eSports competitions affiliated with endemic industry sponsors (e.g., (FIA 2016; Noble 2017; Press 2020)). Each of these communities have groups that participate in threaded online discussions, shared online chat channels, and community portals set up by enthusiasts within a community.

Collaborative learning generally entails locally negotiated communication, cooperation and coordination among collaborators. It similarly benefits from configured arrangements of common resources that facilitate collaboration activities within groups. Communications among group participants may be centered around specific racing games or racing events. Cooperative learning opportunities arise when participants in one community cross-over to communicate or comment on discussions active within another community, where the cross-over brings new knowledge or insight not previously visible in prior communications. Cooperation and coordination can arise, for example, when groups decide to interact or merge their online actions, or to organize racing game events of larger-scale with more diverse resources than each community group typically engage. Collectively, the community of groups like these help to create, promote, translate and situate playing and learning through motorsports racing game culture and practice.

Racing game players also collaborate and compete with automated bots for practice, skill and racing knowledge acquisition. AI-controlled racing bots within motorsports games operate the visual behavior of competing vehicles in support of the human game players who lack the momentary ability to play with others. Competition with bots is also not perceived as socially hostile or costly, whereas play with other human players can sometimes push the boundaries of social norms. But competition with bots can be challenging, yet the level of challenge is a game play parameter that is determined by the player-driver. Motorsports racing games can thus serve as collaborative ILEs, whether the collaborations are through living social groups, or through collaborations facilitated through technological means articulated by automated in-game driving bots.

TBD.6.2 Venues for motorsports game play and/or interactions

What are the workplaces where motorsports racing games and sim racing practice and learning primarily occur? Three venues are common: home, arcade, and professional motorsports team operations center. Simulated racing at home is the largest, most recurring venue for motorsports game play and sim racing. More immersive driving experience is facilitated by a more persistent setup of a sim racing system (cf. Broadbent 2017; Lang 2017; Scacchi 2018). This is true even when the system setup just a personal computer or console, connected to a steering wheel and pedals as user interfaces that substitute for a mouse and keyboard, or hand-held game console controller. So player-drivers need to learn how best to set up and configure their personal sim racing system, and to do so in a home-space that can be dedicated to support sim racing. This may entail acquiring a PC/console that is operated distinct from say a desktop computer or mobile device used to support productivity applications, social media or other non-racing games.

Dedicated sim racing arcades are much more scarce due to the capital investment required for their system configuration and dedicated facilities. Such arcades tend to be co-located with other motorsports themed venues such as professional motorsport racing circuits or automotive museums. Arcade-style street racing game platforms also appear in general-purpose game arcades, but these platforms tend to focus on hedonistic high-flying reckless driving play, rather than serious motorsports racing play.

Last, there are a small number of professional motorsports race team operations centers that locate serious sim racing platforms. In these centers, the sim racing rig is designed, configured, and system settings adjusted to replicate the physical and technical behaviors of the actual race cars employed by the team. These platforms interoperate with the racing telemetry data streams that contemporary race vehicles now utilize, so that sim racing vehicle dynamics can again seek to replicate actual on-track vehicle behavior. These systems are limited to use by professional race drivers or simulator drivers (McLaren 2017), and often represent financial investments in the hundreds of thousands to millions of USD range. However, the capabilities of these professional race team sim racing platforms is such that they inspire some home-based sim racing enthusiasts to emulate, most often through the acquisition of specific racing games that can import and utilize race car telemetry data (e.g., *rFactor 2*).

TBD.6.3. Motorsports racing game genre

What kinds of game genre (or sub-genre) dominate motorsports racing game play? The two most apparent are fantasy street racing and replicated professional motorsports racing. Fantasy street racing games and play are by far the more popular of the two. User experience focuses on recruitment and engagement of fantasy ownership, and potentially reckless driving of virtual cars that resemble either expensive sports cars or other cars that a person may see driving in an urban setting. Street race driving focuses on learning how to win in a street race via virtual vehicle customizations or tuning settings (e.g., virtually add nitrous oxide or supercharger to a vehicle's simulated engine; add larger high traction tires, etc.). Learning also focuses on acquiring expertise for how to perform simulated driving stunts (spinning, flying jumps, careening off other cars/buildings, etc.), or how to rack up massive amounts of simulated destruction via billiard-ball collisions with other vehicles driven by bots or human players.

TBD.6.4 Motorsports racing game content and play mechanics

The visual appearance and observable behavior of a simulated race car matters significantly to motorsports racing enthusiasts. Being able to learn the experience of race driving a car just like the one operated by a top-tier professional racing team, or one that resembles an expensive sports car beyond the financial reach of the player-driver, is an essential element of the simulated motorsports racing experience. Accordingly, the producers of motorsports games typically promote which vehicles (i.e., virtual vehicle models or “skins”) their simulation supports, as a product differentiator—i.e., a player buys a particular game because it offers play with these specific kinds of race cars. Since the potential set of cars is quite large, and game producers must generally obtain a copyright license for use of a professional/corporate racing car appearance, then many racing games provide open-end facilities for players to create their own race car skins, as well as to recreate professional race courses or public roadways that may not be included in the retail version of the racing game, via game modding techniques (Scacchi 2010c; Scacchi 2015).

Career mode play mechanics and advanced skill development are a common feature of computer games that replicate professional sports, as well as of motorsports racing games. For example, in the F1™ 2017 game world, at key points during the regular Formula 1 championship race season, players in career mode are introduced to invitational events during which they will get to drive different classic F1 cars (Freeman 2017). These events focus on developing and refining advanced race driving skills including overtaking challenges, pursuits, checkpoint acknowledgements, proper use of energy recovery-discharge and aerodynamic drag reduction systems, and time attack challenges. Each of these challenges occurs on different race courses with diverse competitive conditions, as well as in cars with different performance and vehicle responsiveness characteristics. Along with driving skill improvements, career mode also requires the need to learn what and how to improve the race effectiveness and durability of the player's selected race car—the car they will utilize through a multirace season when the player pursues a championship career (Smith 2017).

Career mode in F1 2017 requires attention to seemingly pedantic details and idiosyncratic game parameter setting adjustments, generally far beyond the interest of casual racing games and game play. For example, there are more than 100 possible Research and Development upgrades for a selected F1 race car across four different categories: Powertrain, Chassis, Aerodynamics and Durability. For those who don't want to address R&D role playing activities, the player-driver can select the default recommended upgrades. As the player-driver levels-up the career development and experience, the game poses challenges to increase the speed of acquiring and integrating Research and Development upgrades into the simulated F1 race car configuration. The pacing of upgrades is intended to improve management and reliability of your car’s engine and gearbox elements, to improve new upgrade part reliability, and to manage and balance the six key components that make up a modern F1 power unit. Reliability and management becomes uncertain as career advances, allowing for the possibility for upgrades to fail, meaning progress is not always guaranteed when new parts arrive from R&D. Similarly, it is necessary to manage the (simulated) race car's components through a multi-race championship season, reflecting the same kind of situations that arise in the socio-technical world of professional F1 racing as of 2017. In this way, game players must manage usage of all of the individual components that make up a Formula 1 power unit, as well as gearboxes, with race starting position penalties (being placed slower race cars) issued by the game, if a season's allocation is exceeded (Freeman 2017, Smith 2017). In short, mastering game play can become work that requires serious effort and timely attention to detail, much like the real-world of professional motorsports racing. Consequently, the boundaries between play and work become blurred or dissolve altogether as players transition from simulated game play into career development. Game-based ILEs featuring career modes can thus serve as ways and means for playful workforce development within simulated virtual worlds.

TBD.6.5 Game platform infrastructure

Many popular racing games may seem to be all alike to the casual observer or non-gamer.

But the multitude of racing games as a game genre directs attention to the differentiation in game capabilities and platform assumptions. For example, the Gran Turismo series of racing games are designed for exclusive play on Sony Playstation consoles, while Forza Motorsport series operate exclusively on Microsoft Xbox consoles (and also now Windows 10 PCs). These game series respectively represent in the neighborhood of $1B USD in total revenue. However, this also means that enthusiast player-drivers often will own both kinds of consoles in order to enjoy playing each of these games. In constrast, other motorsports games like *F1™ 2019* from Codemasters is available for use on PC running either Microsoft Windows, Apple OSX, or Linux, as well as also on Playstation and Xbox. But only this game is the official licensee of the FIA Formula One Championship Series, the world's largest and most costly motorsport racing series. So player-drivers who play this game can learn a lot about the world of F1, including its business practices, race logistics, driver personal services contracts, vehicle R&D, resource management and more. But little of this may be relevant to other forms of motorsports. The globally popular *CSR Racing* and *CSR Racing 2* street drag racing games share little in common with *Gran Turismo, Forza Motorsport*, or *F1™ 2019*. So what a player learns about race driving skills or knowledge from one game may not inform or subsume what is learned from another game, or a game with different infrastructure requirements or assumptions. Consequently, Racing Games (2019) vary in the racing and computing infrastructure they assume and reinforce. At a different level, the sim racing platform denotes other aspects of racing-gaming infrastructure.

The sim racing platform (or “rig”) is a computer system that engages the full body of the player-driver through multiple user interface devices and activities (cf. Scacchi 2018). Most visible is that the player-driver generally steps into the system, and is thus contained within it—the rig configures a racing seat where the driver sits, facing a force-feedback steering wheel affixed to a stationary surface, along with foot pedals near the feet, and a (simulated car) transmission gear selector within reach. Headphones or nearby speakers provide immersive audio that includes the sound of the race engine, coordinated with throttle pedal and transmission gear selection by the driver. The audio may also include simulated voice instructions from the race team. The simulated race windshield and instrumented drivers dashboard is rendered on the players facing large screen monitor, along with the race driving visual outlook seen through the windshield. The sim racing rig is generally also connected to a wide-area network so that the playerdriver can participant in multiplayer racing games, or organized sim racing competitions (Inside Sim Racing 2019). Rigs with these capabilities are also clustered into local-area sim racing networks in formal racing arcades and training facilities (FIA 2016; Lucas School of Racing 2017; Nissan GT Academy 2017; Scacchi 2018; Watkins 2017).

More advanced and more costly sim racing rigs accommodate up to three display monitors to surround the driver and increase their visual immersion. Alternatively, the driver wears a head-mounted display (HMD) to experience virtual reality race driving immersiveness (Broadbent 2017). Still more advanced rigs incorporate a motion-controlled driver's seat into which the driver must be (restrain) belted—all in service of the player-driver's perceptual engagement and kinesthetic immersion of the simulated race driving experience (Broadbent 2017; Lang 2017). The motion-control seat thrusts/recoils the driver in many directions depending on the driver's driving performance and the race car's simulated physics (e.g., acceleration forces to the side when making a fast turn on the race course, or up/down to reflect race course undulations/bumps (or even curbs or debris that is driven over), and their combinations)-- all with durations of a fraction of a second. As high speed race driving is fast paced, even in a simulated environment, then perceptual and kinesthetic dynamics require the player-driver to learn how to overcome and manage the constant stream of vehicle feedback cues and responses, along with learning how to automatically recognize distractions and hazards from perceivable cues that enable the driver to drive more effectively and more efficiently.

TBD.6.6 Game-based modes of inquiry, interaction and knowledge transfer

Sometimes games provide affordances specifically intended for learning about the subject of the game. Motorsports racing games are no different. The genre of sim racing focus on games that by design are intended to provide players with simulation-based replications of established motorsports activities. Sim racing player-drivers quickly learn to expect to be perceptually or cognitively rewarded for their accomplishments, as well as penalized for their mistakes in judgement or performance. Sim racing games are not designed for hedonistic entertainment that high-flying wreckless driving games offer. Instead, sim racing players get enthusiastic, and will argue vociferously, in demanding authenticity and realism (i.e., verisimiluitude) as a foundational criteria they seek to experience through sim racing. Sim racers attend and view professional motorsports races in order to benchmark and calibrate their expectations for what they want to experience and learn.

Sim racing games generally provide for sustained learning modality via a long duration career mode play experience. Career mode (2020) is explicitly designed and intended for players who want to learn what high performance race driving entails, and how to acquire, deliberately practice and improve the performative skills to do so. This entails extended periods of simulated driving practice with level-specific resources. This requires the player to begin to learn the basics with modest in-game resources, and then earn their way up through skill performance accomplishments to access and utilize more capable racing resources. In motorsports games, this often means you learn to race drive first with a modest, slow car that you must drive to earn experience points and threshold accomplishments (e.g., minimum race course lap time and no collisions when driving alone on a course, for a specified number of laps). Some motorsports games are sufficiently pedantic to require in-game license tests that certify of skill level and commitment to the rigors of accomplished professional-like driver development (Barron 2013).

In motorsports games like F1™ 2019, career mode is more like a role-playing game (RPG). This means that there are many diverse roles to learn about within a professional F1 race team, as well as with race event and team sponsors (Freeman 2017; Smith 2017). Skilled motorsports drivers are expected to be fluent in technical and engineering matters sufficient to discuss and comprehend what team technicians, engineers, and other sim racing drivers want to know for how to improve race car setup and performance. For example, drivers are expected to know how to describe the effects of static and dynamic distribution of weight for their race car after a race driving stint, since changes in matters like chassis suspension adjustments and front/back brake pressure parameter settings can improve or degrade race car balance, performance and handling.

Drivers are also exposed to simulated interactions with sponsors who provide funding for drivers/teams in exchange for service expectations like winning or finishing at the front of the pack. Drivers are also exposed to technical interests, problems, and proposed solutions of technicians and engineers who provide in-game, simulated R&D expertise. More generally, in an RPG, the storytelling narrative that emerges through simulated interaction with other in-game characters, serves as yet another affordance for facilitating immersive experience and situated learning (Bormann, Grietemeyer 2015). Consequently, in sim racing game play, playing to learn is the learning task at hand—playing is learning how to work efficiently and effectively in an agile, adaptive manner. Conversely, the work of high performance race driving is learning how to be a better driver and effective team participant who can communicate problems and potential solutions in domain-specific technology/engineering terms. Sim racing games, game play, and system rigs jointly afford these kind of learning situations.

Learning how to race drive in a multi-driver competition requires willing and able drivers who support the learner. Motorsports games utilize automated bots to drive simulated race cars that create a competitive learning environment for high performance driving. The skill level and competitiveness of the driving bots can be set by the driver-player depending on the skill development challenges they seek. Even full duration races that are scaled to replicate their professional motorsports counterparts may be configured to operate with only the player-driver and the rest bots, a mix of human and bot drivers, or all human players in a live online multi-driver race (Inside Sim Racing 2019). The learning framework that a career mode affords can be further extended and refined about championship series careers. Within a series career, the driver-player seeks to learn the experience of competing in the same race car subject to different settings, on different tracks, with different weather conditions, and with other competitors whose driving performance or simulate race car can change, all across multiple race championship series. This level of simulated racing requires high levels of sustained personal commitment to invested game play and to quickly learning how to adjust to competitive pressures and variations seen in professional motorsports.

TBD.6.7 Socio-technical experiences that bridge physical and virtual worlds

Motorsports games are situated at the intersections of physical motorsports worlds and game-based virtual worlds. What sorts of affordance objects, conditions, or events arise at such intersections, and what consequences do they have for advancing learning about and performing high performance race driving? Clearly, if the intersection is empty, there is no basis for identifying affordances that facilitate such learning. On the other hand, physical motorsports endeavors are expensive and risky ventures that create entertaining spectacle for spectators and enthusiasts alike. So how do motorsports racing games, game play experiences, sim racing rigs, and the game-based virtual worlds they create mediate the expense and risk of physical motorsports in ways the remain complementary to the business interests and spectacle? What affordances do these intersecting worlds embed and manifest? Four different examples are apparent for review.

First, starting in 2008, Nissan Corporation, a global manufacturer of automobiles, has partnered with Sony, publisher of the *Gran Turismo* racing game for the Playstation console to create the Nissan GT Academy. This program, according to Nissan, "...has been defying both common sense and motorsports tradition. The academy takes people who are good at video games and, in a matter of months, helps turn them into professional drivers for Nissan"

(Nissan GT Academy 2018). This “gamer to racer” professional development program opens the door to professional race driving contracts for motorsports game players who have learned how to master race driving skill and knowledge, at least via the Gran Turismo game on a Sony Playstation console, connected to the Playstation Network.

Second, starting in 2017, the McLaren Formula 1™ Team organized a worldwide competition to find the best sim racing gamer. The purpose of the competition was to identify and recruit such a gamer, who would then be offered a professional position with a one year contract on the McLaren Team as its F1 simulator driver (Gitlin 2017; Watkins 2017). The competition engaged more than 30,000 entrants from 78 countries, who participated in online races in either *Forza Motorsport 6, iRacing, rFactor 2, Project CARS, Gran Turismo, F1™ 2017*, and even a mobile game, *GearClub*. The top scoring player from each game was selected as a finalist. McLaren also engaged a panel of motorsports and sim racing experts to help identify and invite another six finalists. The final rounds of sim racing competition were held at the McLaren Technology Center in the UK, before a overall winner was identified (Gitlin 2017). Soon after this competition, long time F1 professional driver on the McLaren Team, Fernando Alonso, announced his financial backing for a new venture to sponsor an Esports team and league tournament play focused on sim racing (Noble 2017). Also in 2017, the FIA Formula One Championship Series launched an Esports program aligned with the the F1 global enterprise for player-drivers of the official F1 2017 racing game. More than 60,000 participants took part in online qualifying race competitions worldwide, playing on PCs or consoles connected to Xbox Live, Sony Playstation, or Steam networks. 40 semi-finalists were selected and brought to play in the Gfinity Esports Arena in London (October 2017) before 20 finalists were identified and flown to compete in the championship race at the Abu Dhabi Grand Prix (November 2017). More than 1M online video displays of the final championship race were watched by spectators on YouTube and Twitch. The 18 year old F1™ 2017 sim racing winner, who otherwise worked as a kitchen manager in Reading UK, soon afterward was given the opportunity to drive physical race car in the Race of Champions motorsports event in Riyahd, Saudi Arabia.

Last, the Lucas School of Racing (2017) supports a driver development program for IndyCar motorsports racing in the U.S. This program, like the Nissan GT Academy, is focused on developing professional racing drivers, specifically for IndyCars. Motorsports racing games like *rFactor 2* are employed by the School with sim racing rigs that employed car and racing data telemetry captured from actual IndyCar races. Noteworthy about the Lucas School is that it's program offered professional training to interested people who want to become high performance sim racing drivers, rather than physical race car drivers.

TBD.7 Establishing the Efficacy of Motorsports Racing Simulators as Constructivist ILEs

As the empirical basis for motorsports racing game play and sim racing is primarily limited to testimonials or informal case studies, then how should the efficacy of learning through such game play and simulated racing platform be assessed? Clearly, the focus here in what is known or knowable from related or aligned scientific studies, rather than merely calling out for future systematic studies involving rigorous experimental controls, alternative intervention treatments, and least-biased participant population samples. So what science can begin to help inform learning assessments here?

First, there have been numerous empirical studies pertaining to the efficacy of modern flight simulators for training military or commercial aviation pilots. Nearly every commercial airline pilot these days has been trained for many hours in flight simulators before they are approved to safely fly human passengers and valuable cargo to distant destinations (Bernard 2012). Historically, commercial aviation pilots were trained in the military. But military and commercial training demands have been at high and growing levels. Thus national militaries were among the first institutions to develop, deploy, and promote the routine training of military personnel in flight operations, and also in servicing aircraft, using aircraft simulators. The apparent success, lower cost, and safety benefits of aircraft and flight simulators also established the basis for similar development and deployment of simulator-based training systems for other large, high-cost military vehicles, nautical vessels, and associated operational equipment. The technologies and capabilities were readily transferred to non-military applications by commercial ventures, and in some situations, even adapted and cost-reduced for application in formal education settings (e.g., driver training simulators for educating new/young drivers). Declining costs, safety, and plausible authenticity of immersive experience were seen as providing obvious value for widespread deployment. Thus widespread practice helped to justify these kinds of learning-based simulation system environments. Similar approaches and outcomes have emerged in the field of medical education as well (Bradley 2006; Lateef 2010). However, understanding what these costs are, and how they may be effected based on alternative configurations of sim racing user interface devices, merits scrutiny as described later.

Second, video games and game-based virtual worlds, their associated user-play experiences, and the comparatively low-cost system platforms provide another basis of learning oriented practice (Scacchi 2010a, Scacchi, Nideffer, Adams 2008). The affordances arising during play in game worlds have helped motivate more rigorous studies of game-based learning and game-based cognition/skill development. A complete review of such studies is not possible in this article, but suggestive studies abound. For example, Green and Bavlier (2012), and Dale, Jossel, *et al.* (2020) systematically demonstrated that action video games, like those involving first-person action play, both require and recruit higher levels of attentional control. Such game play challenge similarly cultivates the ability to rapidly discriminate complex, dynamically animated visual stimuli (i.e., the active game level as rendered on a computer display) to determine or infer which objects merit attention or user control manipulation to successfully advance game play. Challenges like these, when embedded with immersive game play user interface devices and competitive play experiences, offer the potential for enhanced learning and skill acquisition (Hamari, Shernoff, *et al*. 2013; Thompson, Blair, *et al.* 2013).

Other game-based learning experiences that come from environmental enrichments like user interfaces and emotionally stimulating decision-making play experiences, can further embed such learned knowledge deep within neurocognitive capabilities (Clemenson, Stark 2015; Mishra, Anguera, Gazzaley 2016). Similarly, the verisimilitude afforded through motorsports games, game play experiences, and sim racing user interface devices helps links motorsports race driving cognition and high performance driving ability to motorsports cultural practices and neurocognitive activity through symbolic and material socio-technical affordances (cf. Franchak, van der Zaim, Adolph 2010; Gee 2003; Kaufman, Clément 2007; Kreijns, Kirschner, Jochems 2002; Scacchi 2010b; Scacchi, Nideffer, Adams 2008; Scacchi 2018; Wilson 2010). The ability for a user-player to acquire and iteratively improve their ability to manage their attention, encode pre-cognitive reactions and emotionally enriched simulated race driving experiences into deep memories, coordinated with their bodied movement articulation actions during game play, and participatory practices in the sim racing community, are thus a basis for game-based learning. Motorsports racing games, motorsports racing game play in immersive 3D virtual worlds, and sim racing user interface platforms align well with these situations and conditional arrangements.

Another example arises from studies of expertise development and knowledge transfer via video games and game play. Similarly, how the cost function that relates technical capabilities of the sim racing platform to learning, expertise and knowledge transfer outcomes requires attention. Each is considered in turn.

TBD.7.1 Expertise Development

Expertise refers to the acquisition and application of knowledge constructs and skill articulation within a domain where deliberate practice with increasingly difficult challenges is common (Ericsson 2006). Domain or subject-matter experts are a smaller group of people with high or higher levels of domain mastery or master-level skill proficiency compared to people without such expertise. Expertise is video game play or in virtual world navigation and interaction, arises from repeated, deliberate practice and frequent encounter with related, evermore challenging, but as-yet unfamiliar situations within a domain that require action, engagement, or other forms of cognitive-based reasoning. Many video games provide such affordances through multi-level game play, where higher or later levels require expertise and deliberate practice realized at lower or earlier levels (cf. Dale, Jossell, *et al*. 2020). This game play mode is sometimes called skill leveling. Studies of expertise development across large population samples and different games reveals demonstrable, systematic expertise leveling that is manifest and observable in player's perception-action cycle (PAC) times (Thompson, Blair, *et al*. 2013). PAC refers to the duration of time to perceive a game play advancement challenge and to affect the user interaction control movement/selection to addresses the challenge. Experts routinely display shorter PAC times, and the actions they take are more agile, more effective, and more frequent than players with less expertise. Experts know what to do when, where, how and why more often than less skilled competitors (Ericsson 2006). Motorsports racing games, game play and race circuit-practice, and sim racing user interfaces can provide affordances for the deliberate practice and development of motorsports race driving skill mastery and expertise.

TBD.7.2 Knowledge Transfer

If game-based learning can facilitate expertise and play skill mastery, are these knowledge acquisition capabilities transferable to other domains? Knowledge transfer is often cast as a matter distinguishing near transfer from far transfer. Near transfer entails whether knowledge acquired through focused study and practice, can be applied in situations with high verisimilitude to the training/education regime in which they were provided. Far transfer entails the ability to apply knowledge and skills acquired in one domain to another domain that is more conceptually distant and thus affords less verisimilitude to the already mastered domain. An ILE for motorsports driving simulation may afford a high level (or low level) of verisimilitude to actual race driving vehicles and driving experience. Mastering race driving in a F1™ 2019 game may be more readily transferable to sim race driving in an Indy Car game, but of much less relevance in informing how to properly operate and fly in a flight simulator. Control of vehicle dynamics (e.g., steering, braking, acceleration) is a primary skill in all driving and simulated motorsports racing games, but expertise requires awareness and attention to situational variables including vehicular configuration settings (e.g., tire pressure, tread wear, and relative friction/adhesion at appropriate times), on-course position and anticipated maneuvers of competing drivers, weather conditions, the ability to see/feel and follow the optimal racing line at fastest and safest speed possible, and more.

Differences in sim racing platform configuration mediate the transfer of embodied movement articulations, where high verisimilitude systems provide the player-driver with multiple forms of force feedbacks (steering kickback, lateral acceleration forces, vehicle braking deceleration forces, etc.), whereas low-fidelity platforms like mobile devices provide much less driving verisimilitude. Subsequently, game play challenges that require more attention, more cognitive engagement, and more simulated manifestation of physical forces related to vehicle control interaction collectively add to increased potential for the near transfer of knowledge acquisition and skill mastery (Dale, Jossel, *et al.* 2020; Green, Bavelier 2012; Hamaria, Shernoff, *et al*. 2016; Oei, Patterson 2013; Thompson, Blair *et al*. 2013). Again, these factors are readily provided through motorsports racing games, game-based race driving play experiences, and more immersive sim racing user interface platform configurations.

Whether motorsports games and game play can support far transfer is not clear. For example, does a player/driver's motorsport race car driving expertise transfer to different types of vehicles like racing motorcycles, powerboats, or aircraft? Similarly, does it transfer for driving of conventional automobiles in urban traffic situations? Answers are not obvious. High performance perception, attention management, recognition and neuromuscular reaction accommodating agile motorsports race driving, whether with a sim racing environment or physical vehicle, do however point to the need for *deep transfer* of embodied knowledge at a neurocognitive level to demonstrate race driving proficiency and efficacy (cf. Dale, Joessel, *et al*. 2020).

TBD.7.3 Cost Functions for Expertise Development and Knowledge Transfer via Motorsports Racing Simulators

Expertise development and knowledge transfer through motorsports games, game play, and sim racing ILEs come at a price, and the price/cost can vary substantially. Motorsports games are now available for ubiquitous mobile devices (smartphones, tablets) *for free*—zero purchase price. The street drag racing games *CSR Racing* and *CSR Racing 2* are both claimed to have more than 100M downloads, making them perhaps the most popular racing games in the world at this time. In contrast, PC or console based motorsports games can be configured by a userplayer for home, together with user interface devices costing hundreds of US dollars or more (Brennan 2017). More elaborate and capable personal sim racing rigs, for use at home that operate with PC motorsport games, can range in costs from thousands to tens of thousands of US dollars (Lang 2017). Sim racing arcades and motorsports experience centers[2] represent a cost multiple, perhaps indicative of what formal educational institutions may face if they embrace classroom scale simulator deployments. Professional grade racing simulators range from tens of thousands to millions of US dollars. So if the price of sim racing ILEs ranges up to six orders of magnitude (from $0 to >$1M USD), what is the relationship of cost/price to expected outcome, where outcome here refers to motorsports driving expertise and skill mastery?

There are at least three possible relationships, such that the relationship could be *linear*—as when the more one pays, the more one can potentially learn; *exponential*—you must pay an ever larger amounts before you get the incremental outcomes you seek; or *logarithmic*— you pay a little to get a lot, but then must pay a lot more to get ever-diminishing improvements. Additionally, there could be some other cost-outcome function. So what is the best or actual cost-outcome function that is attainable? This is at present the ultimate question on the efficacy of learning a practical subject like motorsports race driving, and whether/how much expertise and skill mastery can be acquired through sim racing at different levels of cost. It is therefore also a question of efficacy of ILEs more generally, along with the extent to which ILEs for a given domain provide varying degrees of immersive experience, authenticity, and verisimilitude through repeated ILE usage and practice, whether playful fun user experiences are accommodated, and at what overall cost-outcome function.

Next, if game-based ILEs appear to offer an attractive cost-outcome function, can these ILEs be made available at affordable cost for deployment in formal education settings where groups of students are to be engaged? Can ILEs be configured for home-based deployment, as has been and is actively being deployed for enthusiast user-player-drivers of motorsports games and sim racing platforms? How best and how affordably to answer these questions is the next challenge to address. The answers produced may then help determine whether and how immersive ILEs, like those for motorsports racing games, game play experiences, and sim racing user interface embodiments, represent the next generation of digital artifacts for empowering interactive learning of subjects and performative skills.

Last, motorsports games and sim racing rigs are not without their technological faults and limitations. They are no panacea as an ILE. A readers of online discussion threads, sim racing blogs, and racing game videos routinely address, the games and rigs are human artifacts that are subject to unexpected operational failures, rig breakdown, and other bugs/faults that totally disrupt an immersive learning experience. Accordingly, one facet of immersive ILEs that merits more attention in the future is what happens when immersion breakdowns or fails in operation. This is certainly an issue for motorsports game developers, as well as purveyors of sim racing rigs, but it also is not something unique to motorsports racing games or ILEs. Thus part of the cost function of any ILE must include costs arising from system failures, and how such unexpected failures can disrupt, delay, or derail the

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[2] For example, see the sim racing arcade by Vesaro Inc. at http://www.vesaro.com/blog/?m=201206 (Accessed January 2020) as well as the i-Way Formula 1 sim racing facility open to the public in Lyons, France, https://www.i-way-world.com/simulation-course-automobile/formule-1/ (Accessed January 2020).

potential of immersive learning.

TBD.8 Conclusions

Computer-based motorsports racing simulation games, game play, and sim racing user interfaces serve as interactive learning environments (ILEs). Such ILEs provide a constructivist learning experience through 3D dynamic graphic animations that are jointly controlled by the underlying game, embedded bots, and user inputs during single or multiplayer game play. First-person perspective racing games can be both fun to play and fun to learn how to master through knowledge and play skill acquisition. But game play-based learning can be demanding, require long periods of practice, commitment and hard work. Whether people who just want to learn how to safely drive an automobile in urban or rural settings may be overwhelmed by the learning capabilities and affordances available in these ILEs is an open question.

Motorsports racing games, game play experiences and sim racing user interfaces are practical as constructivist ILEs. Sim racing is consequential for deliberate practice and learning professional-level skills that enable career development opportunities in the motorsports industry. However, simulator-based learning is also consequential in other application domains, such as for learning life-saving medical procedures and commercial/military aviation flight operations on which many people depend.

Seven kinds of learning affordances associated with Motorsports ILEs were identified and explored for how they facilitate immersive learning. Multiple modes of immersive learning by player-drivers operating within the overlapping worlds of sim racing became apparent including neurocognitive, kinesthetic, socio-technical, and motorsports culture immersion. These diverse modes of immersive learning are experienced through motorsports racing games, race driving game play experiences, and sim racing user interfaces devices collectively provide high-fidelity verisimilitude that participants find appealing and compelling.

Motorsports racing game systems can realize a compelling immersive ILE that facilitate expertise development and knowledge transfer. The expertise that can be acquired through collaborative play and competition can give rise to professional occupational career opportunities. Simulator-based racing thus merits close examination for what kinds of expertise can be developed, and what kinds of skills can be acquired and refined through practice. But these capabilities come with costs that vary by orders of magnitude in USD, depending of the degree of immersive verisimilitude that is provided or can be engaged. How these costs are functional related is unclear and thus merits attention in the future.

What lessons for future ILEs can be derived from the performative experience and socio-technical capabilities arising from motorsports racing games, game play experiences, and simulator style user interface devices? First, low-cost, low-risk immersive 3D, game-based virtual world simulators can be produced for certain kinds of domains for informal education and skill practice at home. Second, these simulators may also be produced and packaged for use in educational institutions that support professional careers within regional or industry-specific workplaces. Such knowledge and skill development will benefit from both playful engagement and sustained multi-level challenge practice. Last, can low-cost motorsports racing simulators and performance driving games be downskilled to accommodate people who just want to safely learn a globally desired practical skill: driving an automobile or similar mobility vehicle in everyday urban/rural environments? This too merits further attention and careful study, both within and across geographic regions and diverse ethnic cultures whose participants want to become novice or professional vehicle drivers.

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